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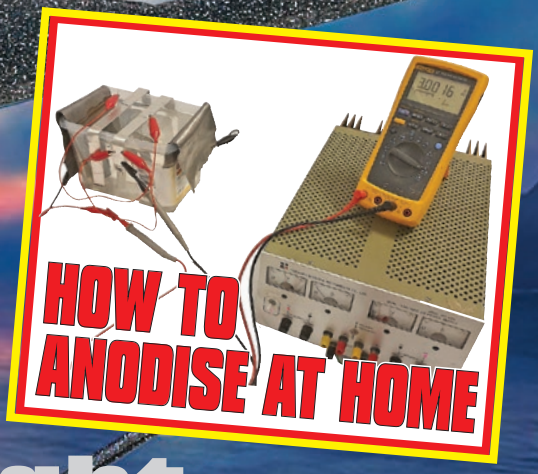
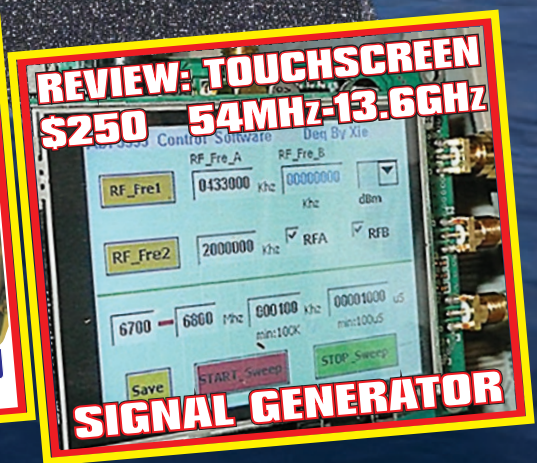


Hiding in plain sight in the Air, Sea and on Land

STEALTH TECHNOLOGY



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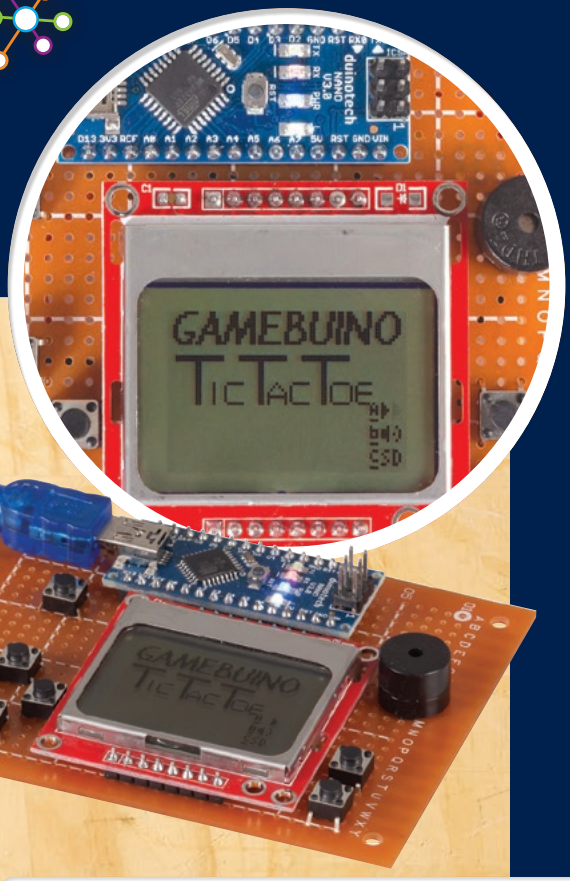
Our very own specialists have developed this fun to build Arduino®-compatible project to keep you and the kids entertained this month.



DUINOTECH Game Machine Project

We found a sweet little game project online http://gamebuino.com, and being open-source, made our own version of it using duinotech parts. What's more, there's already a heap of games that have been created at https://github.com/Rodot/Gamebuino-Games-Compilation, and being Arduino based means you can create your own games too. To get you started, we've built a Tic-Tac-Toe game for it. A bit of soldering and wiring required.

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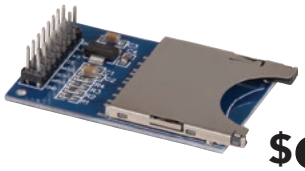

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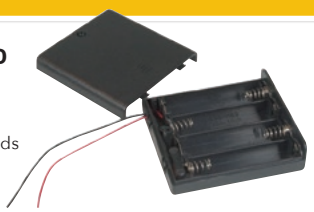

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Contents

Vol.33, No.5 May 2020

SILICON CHIP
www.siliconchip.com.au

Features & Reviews

12 Stealth Technology
They're making aircraft, ships and even soldiers less visible or even invisible to the opposition. The latest techniques used is a story in itself! – by Dr David Maddison

62 New w-i-d-e-b-a-n-d RTL-SDR modules
We decided to put some fully assembled RTL-SDRs through their paces. They cover from low frequencies right through to ultra high frequencies – by Jim Rowe

84 Review: a 13.6GHz Signal Generator for $250?
ADF5355-based modules have taken signal generators up to a whopping 13.6GHz – with touchscreen control! And all this for around $250 – by Allan Linton-Smith

100 A high-performance tweeter that's just 6.7 x 4.7mm!
New MEMS (Micro Electrical Mechanical Systems) tweeters have just as much in common with SMD components as traditional speakers! – by Allan Linton-Smith

Constructional Projects

26 YOU can anodise aluminium at home!
All it takes is a decent DC supply (an old ATX computer supply?), some easy-to-get chemicals and some hardware you probably already have at home – by Phil Prosser

36 H-Field Transanalyser for AM radio alignment & service
Build one of these and you'll take all the guesswork out of AM radio building, testing or alignment. Great for transistor radios; can do valves as well – by Dr Hugo Holden

68 An altimeter for your . . . car?
Ever wondered as you're driving along just how high you are above sea level? This dash-mounted project adapts an earlier plane/ultralight altimeter and gives you a readout in feet or metres plus touchscreen control – by Peter Bennett

88 A DIY Reflow Oven Controller – Part 2
We've got the cheap toaster oven. We've made the cheap controller. Now we're almost ready to start soldering SMDs! – by Phil Prosser

Your Favourite Columns

46 Serviceman's Log
A shed full of tools . . . by Dave Thompson

79 Circuit Notebook
(1) 3-output power supply using plugpacks
(2) Variable speed discrete reversing LED chaser
(3) Proximity warning for the blind
(4) Simple "emergency" charger for small batteries

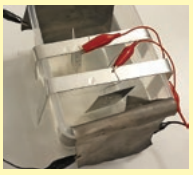
96 Vintage Radio
Toshiba 9TM-40 "robot" radio – by Ian Batty

Everything Else

2 Editorial Viewpoint
4 Mailbag – Your Feedback
61 Product Showcase
105 Ask SILICON CHIP
108 SILICON CHIP ONLINE SHOP
111 Market Centre
112 Advertising Index

How DO you make a plane, a ship or a soldier invisible? Stealth techniques are improving all the time – Page 12

Anodising aluminium panels and parts at home is not that difficult with the right components – and knowledge! Here's how to do it – Page 26



This H-Field Transanalyser makes testing and aligning AM radios a snap! If you're into Vintage Radio or any AM radio work, you really do need one of these – Page 36

New wideband RTL-SDR modules go down to kHz and up to GHz. They're a great (and inexpensive) way to listen to what's on the air . . . anywhere! – Page 62

Yes, it fits in your car dashboard and gives you your current height above sea level – Page 68

We're finishing off our new SMD reflow oven – and showing you how to use it! – Page 88

Would you believe this is a high performance tweeter? You'd better – at 6.7 x 4.7mm, it's one of the new breed of MEMS devices that you're going to hear a lot more of – Page 100

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Subscription rates (12 issues): $105.00 per year, post paid, in Australia. For overseas rates, see our website or email silicon@siliconchip.com.au

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ISSN 1030-2662
* Recommended & maximum price only.

Printing and Distribution:
Spotpress
24-26 Lilian Fowler Pl, Marrickville 2204

Editorial Viewpoint

Finally . . . an article that isn't (just!) about the virus . . .

First, I probably should explain that we are (at the time of writing this) still in operation, despite the doomsday virus. We're doing our best to make sure that all readers can still get the magazine.

As long as our printers can print it and Australia Post can deliver it, you'll continue to get it. Never has being a SILICON CHIP subscriber made more sense!

And if you usually buy it from your newsagent but can't now, just order a copy (best way is via our website) and we'll send it out. We've reduced the price so it won't cost you any more (well, maybe a bit more if you're in New Zealand).

We explain our special "anti corona virus" offer in more detail on page 35.

If for some reason we can't send out magazines for a time, we have plans in place to make digital copies available until the situation is resolved.

With that out of the way, what I really wanted to write about this month is why you might be interested in buying copies of our older magazines in PDF format (see page 95 for details on this offer).

Highlights of the PDFs on USB

One of the major reasons you may wish to purchase SILICON CHIP PDFs on USB (which also gives you download and online viewing access) is that for every level of electronics involvement, SILICON CHIP makes a great reference. If you're designing your own circuits, you can often find useful snippets in our projects and also in Circuit Notebook. And it's much easier to look stuff like that up electronically rather than in bulky paper copies.

You can print out any pages that you might need, for example, if you want to build one of our projects.

But there's also a lot of great content from the magazines way back in the 80s and 90s, even if some of the projects from those early issues are now obsolete (not all are; you might be surprised!).

For a start, every Serviceman's Log column is highly entertaining. When life returns to normal, I plan to go through and read them all from the start. It doesn't matter that so many of them are stories about servicing now-obsolete CRTs, VCRs etc. It's still fascinating to read about the Serviceman's approach, the customers, the various pitfalls along the way, and the (usually) happy ending.

Then there's the 24-part Story of Electrical Energy, starting in July 1990 and finishing in June 1993. Much of that is still relevant today (and even if not, still very interesting).

Similarly, the 29-part series on The Evolution of Electric Railways from November 1987 to March 1990 is a fascinating read, whether you're heavily into trains or not.

Neville Williams, of EA fame, wrote a column called The Way I See It for SILICON CHIP from November 1987 to December 1989. It's a bit off the beaten path, but nonetheless can be quite thought-provoking.

Some of the early computer stories are interesting, just from a historical perspective. I had forgotten how primitive – and expensive – PCs were in the late 80s and early 90s!

There's a lot more worth reading about, but I've run out of space (I blame the coronavirus). Anyway, purchasing our PDFs on USB not only gives you a great way to spend time if you're stuck at home, but it also helps us keep your magazine running during these difficult times.

Regardless, if you do buy them, I hope that you get lots of enjoyment from them.

Nicholas Vinen

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Medical thermometer accuracy

In this current crisis, there is a chronic shortage of thermometers, and many of them may be inaccurate, as I pointed out in my article on thermometer calibration (January 2020; siliconchip.com.au/Article/12230).

Many cheap digital thermometers are only accurate to ±2°C, and in some cases can be worse than that. Even branded thermometers from pharmacies and hospitals can be inaccurate. You don't want to get a high temperature reading and worry that you may be sick, only to find out that the thermometer was reading high!

We have an infrared thermometer. This cost me $15 some years ago (currently they cost a minimum of $80) and I checked it on the calibrator as being accurate to within ±0.5°C. We just point it at our foreheads, and we have been checking ourselves every day, even though we know we are well. Our temperatures vary quite a bit, depending on the time of day and whether we have recently eaten.

Now we have a baseline for our own healthy temperature, so if we do contract the dreaded virus and our temperature increases, we will know instantly that we are in trouble.

I guess there are many people out there who worry a lot about their health (especially in the current environment) so I can only stress that you need to set your baseline when you are healthy. It doesn't matter what sort of thermometer you use, as long as you use the same one!

Allan Linton-Smith,
Turramurra, NSW.

Nicholas comments: we bought a medical forehead thermometer from Chemist Warehouse when our first daughter was born, and I consider it a good purchase, despite the relatively high price.

It gives very accurate and consistent results (she normally measures 36.9-37.1°C) and have you ever tried to hold a thermometer in a toddler's armpit for 30 seconds? A quick swipe of the forehead is much easier!

You do need to make sure to follow the instructions carefully, though. If used as per the instructions, it works very well, but if you do it wrong, the results can be way off. You have to hold it (gently) in the middle of the forehead, press the button, then quickly sweep it across to one temple and then back to the other.

Help wanted and parts to get rid of

I have been given a high-quality Grundig CF11 cassette deck which I would like to use, but it needs a set of drive belts. I have not had a lot of luck in obtaining suitable belts here or overseas, and wondered if any readers could suggest a source.

Also, we recently purchased a 1994 car which had an engine immobiliser fitted from new. The documents indicate it was installed by Fortronic Forcefield Car Security Systems. All contact listings in the paperwork for them are no longer valid.

I wonder if any readers know anything about these systems and particularly, how to bypass or disable them. The way it operates is that a 6.35mm phono plug is inserted into a stereo headphone-type socket on the dashboard and then removed. We then have 60 seconds to insert the ignition key and start the car.

I see no brand on the immobiliser module. The phono plug measures 9kΩ tip to sleeve, 13kΩ ring to sleeve and 22kΩ tip to ring. We have three plugs which all measure the same, but one does not work; that's a separate puzzle. I would be grateful if anybody had any information.

Finally, after 50 years or so of being an electronics hobbyist and building of many loudspeakers, amplifiers etc from magazines like *EA* and SILICON CHIP, I am reaching a point where I cannot continue this at the same pace. I have the inevitable collection of bits and pieces left over from projects that will not proceed as things are changing so rapidly in our modern world.

Rather than just dump all this stuff into a wheelie bin, I would like to see if any enthusiasts want all/any of it at very nominal prices. If anyone is interested, please e-mail me as I can send a full list back as an e-mail attachment for perusal. It's a mixture of mostly new parts and a small number of used parts.

I'm selling the items on an as-is "lucky dip" basis, and I am not offering returns/refunds. I am happy to strike an overall price or a price for groups of items, but do not want to sell them individually.

The list includes 8Ω l-pads, panel meters, 25 & 50W resistors, fuses, crossover PCBs, diodes, regulators, transistor mounting hardware, polyswitches, speaker connector strips, headphone sockets and plugs, RCA socket plates, plastic and aluminium knobs, Jiffy boxes, 100V line transformers, CB microphones (still in bubble wrap), heatsinks, RCA leads etc.

Ranald Grant,
gowrie900@gmail.com
Bellbowrie (Brisbane), Qld.

Keith Rippon highly recommended

Thank you for your suggestion to use Keith Rippon who advertises in your Market Centre section for kit construction. He did a very good job, purchasing a Colour Maximite kit for me, then building and testing it. I am very impressed.

Ric Mabury,
Melville, WA.

Replacing SLA batteries with $LiFePO_4$

I would like to see a project that allows modern battery chemistries to be used to replace SLA batteries. This

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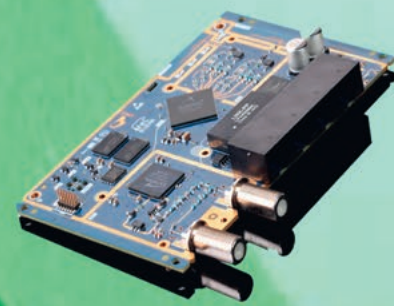

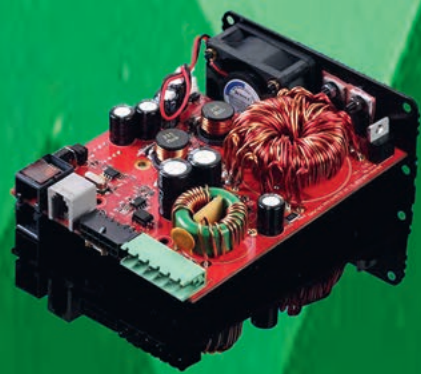

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would provide a longer run time but circuitry would be required for proper safe charge and discharge of a newer type cell pack, when the original product circuitry was only designed to handle the sealed lead-acid type.

I am thinking that the 12V 7Ah batteries that are used everywhere from small UPSs for computers, the NBN, alarm systems etc, could be replaced with more modern $LiFePO_4$ or other cells.

Les Clark,
Donvale, Vic.

Response: we haven't published such a project, and it is a good idea. However, note that there are many 12V $LiFePO_4$ batteries available that are designed to be direct drop-in replacements for SLA batteries. These can be charged using the SLA charger and in most cases, will not require any modifications to the equipment. This includes Jaycar Cat SB2210 (12.8V 7Ah).

Dead simple speakers for a PC

I have been dissatisfied for some time with the quality of sound from my computer speakers. I don't have room for a full audio system with amplifier and bookshelf speakers, so I came up with another solution.

I found a tiny "full range" driver from Peerless, model TC5FB00-04, and mounted a pair in Jaycar Cat HB5040 diecast aluminium boxes (115 x 65 x 55mm external, internal volume of 0.28L).

To drive these, I installed a Creative Labs Audigy Fx Sound Blaster card in my computer. I found that I had to disable the onboard audio in the BIOS to avoid conflicts. The output impedance of this amplifier is 18Ω, which affects both the frequency response and the volume when driving 4Ω voice coils.

I adjusted the software equaliser to +24dB (maximum) down to 500Hz for more volume, but reduced it to +12dB at 250Hz to compensate for the 250Hz resonant peak in the response curve. All frequencies below this are attenuated to protect the speakers.

I mounted two 3.5mm stereo sockets in parallel on the back of each box so that I could daisy-chain them from the computer, thus simplifying the connections. Of course, you cannot get any deep bass from such small speakers, but what you get is good clean sound without cluttering up your desk.

Philip Badham,
Balcolyn, NSW.

MEN vs other systems

I have an idea for a future article for your magazine, which would be about different mains standards around the world, discussing the pros and cons of each. Also, I believe that I have an idea on how to make the MEN system safer and I would appreciate your thoughts on it.

It was sparked by a letter someone sent to a magazine that I get as part of my electrical registration. This person was promoting a standard called TNS to replace MEN. In a nutshell, this involves removing the Earth stake and the Earth-Neutral link at the premises, then connecting the premises' Earth connection to a wire which connects all the way back to the supply transformer Earth.

This means running another wire (a fifth wire) down the street which (I guess) is a shared, dedicated Earth wire. Personally, I think this sounds pretty scary.

The author (who is an Electrical Inspector) sounded quite passionate and was encouraging others to get behind him to endorse this change. I currently won't be, but, I would be interested in your thoughts (and others) on this. It was an interesting article, and it did make me think, but I think that this proposed TNS system would be more hazardous than MEN.

That's because the integrity of the single Earth connection at the transformer would be vital. If it was at all compromised, it would not be immediately obvious (which is the same problem as a Neutral link failure in MEN). If any of these houses had a Class I appliance that developed a live conductor to chassis fault, it would result in every Class I appliance of every premises on that circuit becoming live.

TT (or Tera Tera) was another standard that was proposed (here in NZ) from this same magazine, though this was quite a few years ago now. TT keeps the Earth stake at the house, but the Earth-Neutral link is removed. It relies on every circuit being RCD-protected. This system sounds quite good, but, the TNS-proposing article did raise a drawback of TT, which is that the RCDs require regular and scheduled testing.

The existing MEN system has certainly stood the test of time, at about 90 years (in NZ anyway). Every house or dwelling is effectively its own 'island'

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from an Earthing/safety perspective, and a fault in any dwelling is not likely to affect any of its neighbours.

It would be interesting to know how many fatalities have been caused by Neutral link failure in the past 90 or so years. I'm guessing that the figure would be very low.

I can't help but think that in the 21st century, we could be making use of smart electronics to make the MEN system safer. This could be done via smart meters. The smart meter could be extended to monitor Earth leakage current and to log and report this back whenever the meter is read.

Grant Saxton,
Cambridge, New Zealand.

Response: we can see the logic in running a dedicated Earth wire in the distribution system, but can't see why the premises can't also have local Earth stakes for redundancy. The centralised Earth connection is a potential point of failure, but it would be much easier to check and monitor than thousands of distributed Earth stakes.

Some smart meters can already monitor for Neutral link faults. This is currently being rolled out in Western Australia. We welcome reader feedback on these ideas.

Mains monitor wanted

I've been following the discussion in the last few issues over power problems caused by faulty Neutral connections and was wondering whether you could publish a project for monitoring power quality. It could send the data out via a serial or USB link to allow it to be interfaced to an Arduino, Raspberry Pi or whatever.

I'm of thinking something like the PZEM 004T available from various sellers online, but it would be nice if it was significantly less likely to kill you than the PZEM is!

Peter Gutmann,
Auckland, NZ.

Response: another good suggestion. We do have a mains monitor on our list of future projects, with a note that it should log to an SD card and have a battery backup, so you would have a record of blackouts, brownouts etc which have occurred.

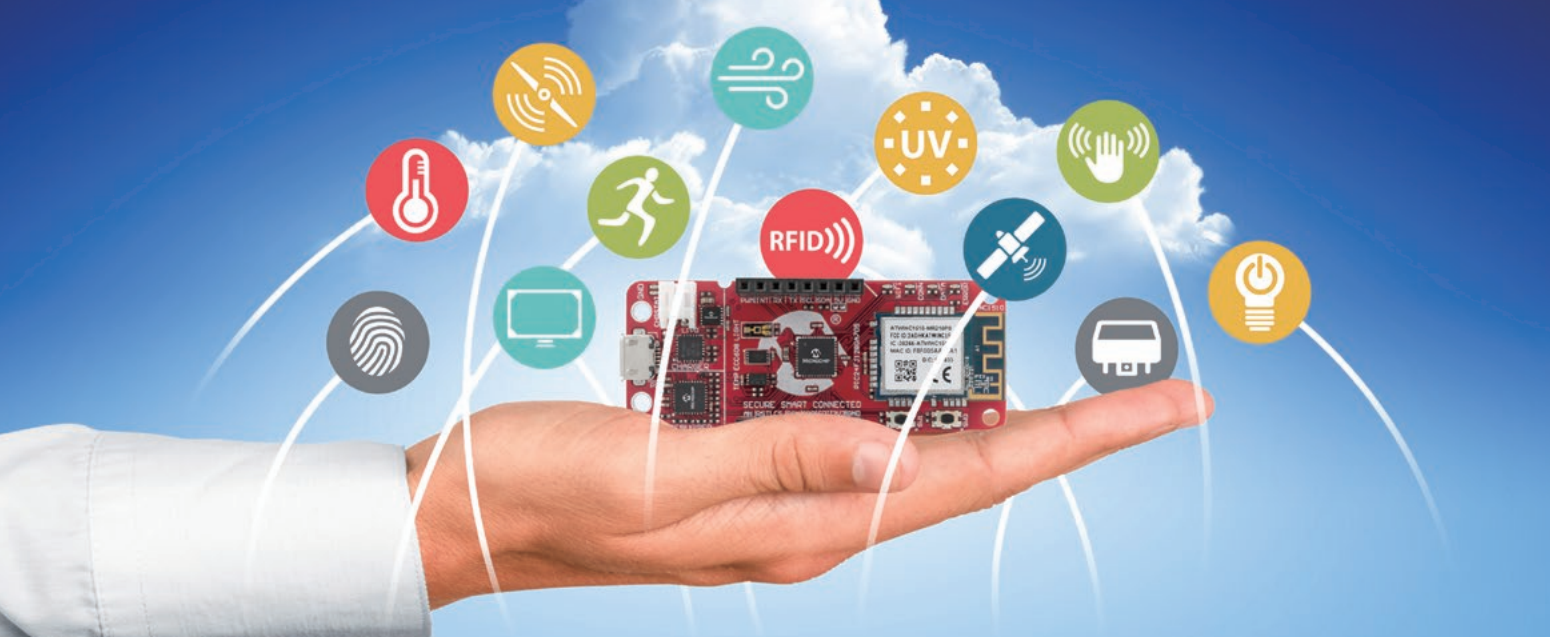
Comments on the March issue

I enjoyed reading Tim Blythman's article, "An Arduino Retrospective" (siliconchip.com.au/Article/12575). Even though I have no intention of ever using an Arduino controller, I read the article with considerable interest because I have been curious about their background for some time. However, I did regard his use of the Basic Stamp 1 as a benchmark as misplaced.

There were a large number of developmental boards available almost from the first days of micro-controllers, and the Basic Stamp only appeared in the early 1990s. The manufacturers even made a couple of microcontrollers with on-board BASIC interpreters, namely Intel's 8052 ROM BASIC and Zilog's Z8671PS with BASIC and Debug.

Unfortunately, it was difficult to "talk" to these boards in the early days. Either the board used a hex keypad and seven-segment display or required a Teletype for communication via a serial link. Even then, loaded programs were not permanent without battery backup or "burning" into EPROMs. Certainly, the Basic Stamp made life easier in that respect.

Basic Stamps are still available and are very easy to use. They have survived for quite some time, and I suspect they will continue for a while yet despite the availability of the PICAXE, Micromites and others. It will be interesting to see



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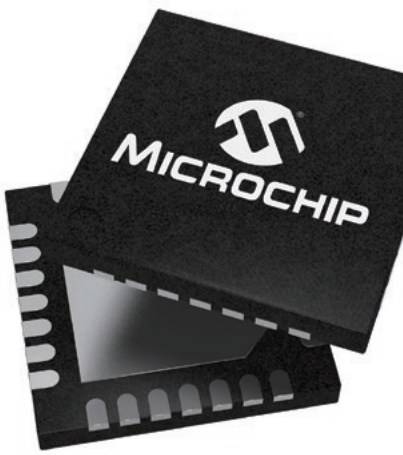

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how long the Arduino series lasts. Will the large number of available "shields" be a sufficient advantage to ensure its continued existence?

The 1000:1 AC EHT Probe for Ignition Systems by Dr Hugo Holden (siliconchip.com.au/Article/12587) is a gem of a project. SILICON CHIP presents plenty of audio and micro projects; some are interesting and some are not, but projects like this are in a league of their own. I have no use for it at the moment, but it doesn't matter. The design consideration and details are what makes it a fascinating project.

The use of the brass rod as a distributed capacitance appeals to me for both its novelty and its simplicity. I hope that SILICON CHIP can attract and publish more of these unusual projects. They add a bit of technical spice compared to the run-of-the-mill projects.

It is nice to see that you are offering PDFs of the early issues. I am interested, but undecided as to whether I should buy the blocks that contain the issues that I do not have. I have downloaded a large number of early issues of other magazines from http://archive.org over the years, and have found that only a very small number of articles or programs are of interest.

The price will be a factor in my decision, but it is not objectionable. I have scanned plenty of my own material for backup and also for ease of reading, so I fully understand the amount of time and effort required. What PDF readers can access the files, and if firmware is required for an early project, is it available?

George Ramsay,
Holland Park, Qld.

Nicholas comments: We're glad you enjoyed the magazine. You are right that Dr Holden's probe is a great project. It gives us insight into the intricacies of high-voltage design that we are generally not exposed to.

Regarding the PDFs, you can read them with just about any PDF software.

You're right about the work involved in scanning. The older magazines are in a very poor state and the print quality in those days was inconsistent. So it's a lot of work to clean them up to get a good result. I estimate we've put 8-10 hours of work into every magazine we've had to scan, and a similar amount for those which have been digitally re-created.

The results are amazing, though; even for the magazines published in the 80s, it's almost like reading a brand new magazine.

We don't include firmware and other downloads on the USB drive, but purchasing it does give you access to download all the relevant files (where available) from our website. We've put everything up there that we can find. You could, of course, save them to the USB drive.

It should be noted that most files from before 1993 were not archived as they weren't done on computers, so PCB patterns from before then are typically not available separately. Similarly for firmware, although back then source code was printed with the article.

See my editorial this month for some articles in the earlier magazines that I think you (and many others) will enjoy.

Vintage radio 'hash filters'

I would like to make some comments on the Vintage Radio article for December 2019 (siliconchip.com.au/Article/12183) and John Hunter's letter to the editor in the February 2020 issue along with Ian Batty's additional reply (Mailbag, p10).

In the Ferris 106 article, on page 101 there was a reference to the purpose of coil L1. The explanations by Graham, John and Ian make me wonder if any are totally correct.

I remember when I was doing car radio service back in the 1960s that the tuned circuit, which would be the combination of both windings of L2, could not be peaked if a long coaxial cable was connected from the set to a remote 6-9 foot (1.5-2.3m) Walbar antenna. The impedance of the coaxial cables used was approximately 110Ω, keeping the capacity between the inner and the outer to a minimum.

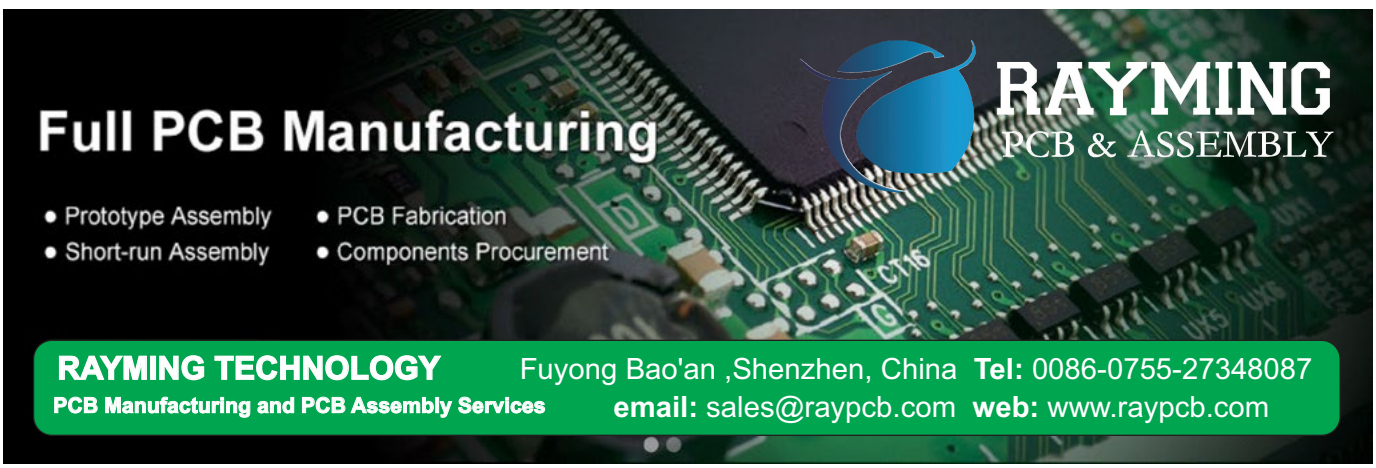
It was necessary to put a capacitor in series with the inner of the coaxial cable so that the circuit could be tuned up properly. I don't remember the value of the capacitor.

All the information available to me at the time indicated that L1 was a hash or ignition filter. I never questioned that, and I imagine most didn't. John, in his Mailbag letter, said that he believes it to resonate at 40MHz, as per the information in the Radiotron Designers Handbook.

I don't know if the editors got it right in the Handbook, as I have found several errors in their conclusions in some areas. However, it may act as a low-pass filter with a cut-off frequency around 40MHz.

I gather the idea is that the interfering spikes from the vehicle ignition system (quite ferocious in those days) would be clipped, and not transfer readily across the circuits to the grid of the RF stage. So it may be a combination of what Graham and John say.

Ian provides another scenario, and uses the example of the Krielser 41-21



which has a 100µH coil shunted by a 3.9kΩ resistor. The purpose of this coil/resistor combination is to act as a low-Q loading coil in series with the antenna, to provide a modest boost to signals at the lower frequency end of the broadcast band, to help the rather short antenna that is commonly connected to receivers since the 1950s.

The same principle was used with the mobile high-frequency antennas used on RFS or CFA transceivers back in the same era. Without such a coil in the antenna system, the mobile two-way radios were almost useless.

I sometimes used to remove these components as I thought they would cause a problem and didn't have any way to test their effects properly. These days, I could do much better tests. One way of finding out is to intermittently short out these components in a typical situation, and observe what changes there are to the performance of the radio.

A car radio of that era would need to be fitted to a vehicle from the 1950s to 1960s, when ignition noise was severe, as later vehicles have much better ignition suppression and L1's purpose may not be evident in later vehicles.

Rodney Champness,
Mooroopna, Vic.

Want to buy an argument?

Regarding the Ferris 106 Car Radio article, I too restored such a radio many moons ago. I recall noting the existence of inductor L1 in the antenna circuit at the time and thought about its function for about 30 seconds. Not being able to figure out why it was there definitively, I concluded that the designers obviously knew more about it than me, so I gave it no more thought and got on with the job.

I was rather bemused to find three columns of argument over this device in the February 2020 issue of SILICON CHIP. It reminded me of a column run by the late Neville Williams in *Radio, Television & Hobbies* titled "Let's Buy an Argument".

Neville would pick a subject (sometimes obscure), throw it out there and watch all the "experts" come out of the woodwork. It was informative as well as entertaining. Perhaps SILICON CHIP could revive the idea.

In the meantime, I will leave you with the following to ponder. It came out of The University of Melbourne Physics Department about 40 years ago while having a conversation with some of the Electronics Workshop boys.

If we take two metal kettles and connect one to the anode of a battery and the other to the cathode, boil both kettles over a gas flame and combine the steam, would the ensuing thunderstorm kill all the flies in the room?

Brian Smart,
Myrtleford, Vic.

The history of Pye is complicated

I just read the article on the restoration of a 1946 Pye Technico model 651 in your February 2020 issue. The author included a section titled "What happened to Tecnico?". I disagree with his comments that their products "… were made from designs used internationally by Pye". All Pye radios and TVs made in Australia were local designs.

He also commented that "The Pye company became over-committed to TV products in the 1960s and collapsed, leading to the closure of Pye-Technico as a radio manufacturer in 1967".

However, Pye designed and produced what was the world's first successful all solid-state large screen B&W TV. They also continued to make radios in stereos (eg, Pye Black Box) right up to the start of colour TV in 1974. The last indigenous design Pye TV, the T34, continued in production until late 1979.

Ian Robertson,
Belrose, NSW.

Response: we asked Graham Parslow about these inconsistencies, and his response was as follows.

Ian is correct to challenge my implication that the Tecnico facility in Sydney moved to use Pye designs from international sources, to the exclusion of Australian designs. The Pye-branded Ranchero radios made in Sydney from 1958 onwards were entirely Australian designed and manufactured.

The change from being Tecnico to Pye at the Sydney plant can be seen in the change between 1958 and 1959 in the wording of chassis product information on the Ranchero radios. The wording "Manufactured by Tecnico, a product of the Pye group of companies" became just "Pye Industries Ltd Sydney".

The UK Pye company became insolvent in the 1960s by a series of failed ventures, including overcommitting to R&D on studio TV technology. Even so, Pye had many successful consumer products, with the outcome that Pye International moved to ownership by Philips from 1967.

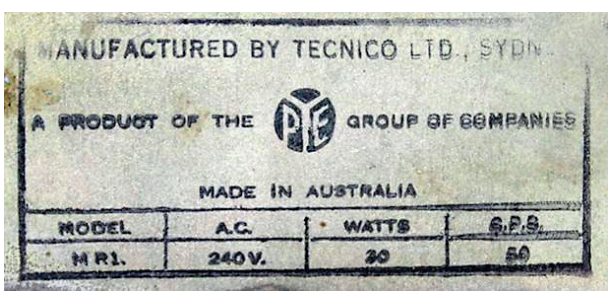
Philips saw merit in keeping the successful Pye brand and giving design autonomy to units like the Sydney plant. Radios as separate units were discontinued in 1967, while TVs continued to be designed and manufactured, as Ian Robertson has related.

Wireless trailer lights wanted

I noticed an article for wireless trailer lights in Nuts & Volts magazine (USA). How about publishing a similar SILICON CHIP design? It looks simple enough.

Paul Cahill,
Balgal Beach, Qld.

Response: that's an interesting idea. We're investigating it to see whether it is viable. It would probably have to be restricted to lighter trailers that don't have or need a brake servo. SC



The history of Pye: how the badges on the Ranchero radios by Pye differed in attribution between 1958 and 1959.

STEALTH TECHNOLOGY

Stealth or "low observable" (LO) technology involves making vehicles or craft less visible or even invisible. It can be used by military, police, coast guards (and the people trying to evade them!), hunters, photographers etc. It encompasses a range of methods designed to reduce the detectability of ships, submarines, aircraft, land vehicles, missiles, space vehicles, buildings, people and any other item that is to be concealed.

Vehicles, people and munitions can be detected by a variety of means. This includes visually, from infrared emissions, electromagnetic emissions, sound, wakes, reflections of radar, lidar or sound waves (SONAR), or by any other process or energy emission that will reveal their presence.

All these factors combine to produce a detectable "signature". Stealth technology is all about reducing that signature.

Stealth can be achieved through active and passive electronics, material composition, surface treatments, object shaping, colouring, lighting, heating, cooling and acoustics. Tactics are also important (eg, which altitude an aircraft flies at, or which path a human takes through terrain).

All elements of the signature must be addressed for proper stealth.

As with most technology, implementing stealth is not a once-only strategy. Detection technology is also improving all the time.

Weaknesses are always being found in concealment and measures for finding the concealed platform, so ongoing development is required for both sides.

Indeed, countries which have developed the best stealth technology likely also have excellent detection technology. Otherwise, they could be surprised by attacks using stealth technology that they didn't know their enemies had.

by Dr David Maddison

History of stealth

Apart from camouflage clothing, which has been around since pre-history, one of the first attempts at stealth in the modern era was in WWI. Germany experimented by using transparent fabric on its aircraft, to make them less visible to the human eye. Interior parts were painted in light colours to help hide them (Fig.1).

Similarly, in 1935, the Soviets modified a Yakovlev AIR-4 to make the Kozlov PS (or Prozrachnyy Samolyot), a transparent aircraft.

During WWII, Germany experimented with stealthy anti-radar and anti-sonar coatings on its submarines.

The German Horten Ho 229 from WWII was a 'flying wing' type aircraft developed late in the war. Flying wings are intrinsically more stealthy than conventional designs, but its shape was dictated more by fuel efficiency than stealth (early jet engines were very inefficient).

In 2008, Northrop Grumman reproduced the aircraft and tested its radar cross-section, determining that it had a detection range 20% less than a conventional WWII fighter. Combined with its very high top speed, it could have changed the outcome of the war had it been produced in sufficient numbers.

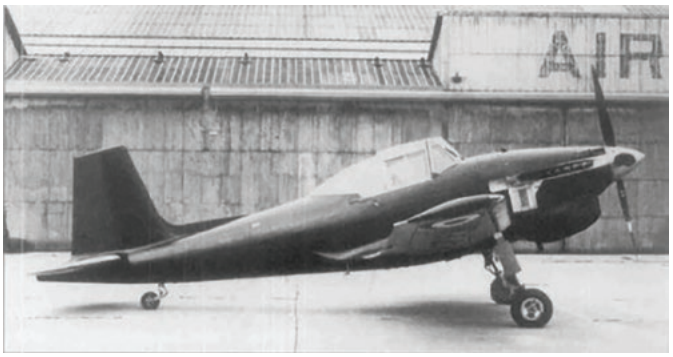


Fig.1 (left): artist's concept (bottom) of German "invisible" plane from WWI. *Image source: siliconchip.com.au/link/aaz5*

Fig.2 (above): the 1950 Boulton Paul Balliol with DX3 radar absorbing material.

See the video titled *"Stealth Fighter Greatest Mysteries of WWII Hitler's Secret Weapons Recreated"* at **siliconchip.com.au/link/aaz9**

Also during WWII, the Germans used anti-sonar tiles on submarines. The Soviets adopted them in the 1970s, and the US and UK from the 1980s.

In 1945, the US Massachusetts Institute of Technology (MIT) developed radar absorbing-paint for aircraft. The paint was known as MX-410 and contained disc-like aluminium particles in a rubber matrix, but it was too heavy to be practical.

The British Boulton Paul "Balliol" first flew in 1950. It could be regarded as the first aircraft with radar stealth properties (Fig.2). Two were used to test radar-absorbent rubber-like "DX3" coating materials in the 1950s. It was designed to defeat radar in the X band, 8-12GHz.

Following the Balliol, the British also tested DX3 on a Canberra bomber in 1957, designated WK161. Testing continued until 1963. It also had a special engine nacelle design to reduce radar reflections from the jet turbine.

After the shooting down of the American U-2 spy plane over the Soviet Union in 1960 and the capture of its pilot, Gary Powers, it became urgent for the USA to develop anti-radar stealth technology. This lead to the stealthy Lockheed A-12 and its descendant the SR-71 Blackbird (Figs.3-5), and subsequent aircraft discussed below.

The SR-71 Blackbird flew from 1964 to 1998. It had features which gave it a low radar cross-section at the high altitudes it flew, including paint that contained ferrite balls, rudders canted at 10° and alternating wedges of titanium and honeycomb plastic composite material on leading and trailing edges, to break up radar signals.

The 'father' of modern low-observable platforms

An important area of stealth technology is the interaction between radar beams and vehicle surfaces.

It was a Russian, Pyotr Yakovlevich Ufimtsev, who established the theoretical basis for the reflection of electromagnetic radiation from various objects. The Soviets permitted him to publish his work as they saw no military or economic value in it.

The English title of the book he published in Russian in

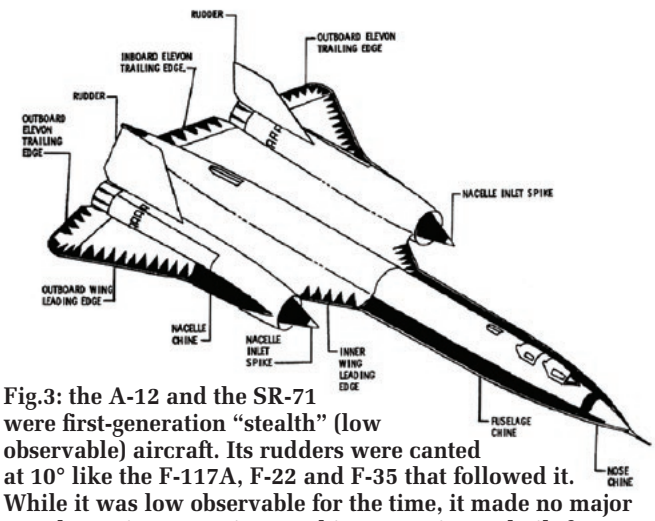


Fig.3: the A-12 and the SR-71 were first-generation "stealth" (low observable) aircraft. Its rudders were canted at 10° like the F-117A, F-22 and F-35 that followed it. While it was low observable for the time, it made no major aerodynamic concessions to this aspect; it was built for speed.

Fig.4: an SR-71 Blackbird under construction, showing the wedges in the wing trailing edges (from siliconchip.com.au/link/aaza).

Fig.5: the US SR-71 in flight. The history of stealth and the Blackbird is covered in the book "From Rainbow to Gusto: Stealth and the Design of the Lockheed Blackbird" by Paul A. Suhler.

1962 was "Method of Edge Waves in the Physical Theory of Diffraction", and it was translated by the US Air Force and published in 1971. You can download a free copy via http://siliconchip.com.au/link/aazb

The book caught the attention of American engineer Denys Overholser at Lockheed. He realised that it provided the theoretical foundation to build a stealth aircraft, which lead to the development of the first operational stealth aircraft, the F-117A (Figs.6 & 7). Its development started in 1975, and a demonstrator first flew in 1977. It was not known to the public until 1988.

Engineers at Northrop also used the theory to program supercomputers to optimise the design of the B-2 bomber (Figs.8), a much more sophisticated design than the F-117A. This was because the computer power to implement the B-2 design was not available when the F-117A was designed.

Fig.7: the US F-117A flew from 1981 to 2008. It was the first purpose-built production stealth aircraft, designed to have a low radar and infrared signature.

Fig.6: the Lockheed "Have Blue" HB1001 proof-of-concept stealth technology demonstrator. It was developed into the F-117A Nighthawk which first flew in 1977 and was the first aircraft whose shape was specifically designed to minimise radar cross-section. Two prototypes were built; both crashed, but the stealth concept was proven.

The B-2 is highly aerodynamically efficient, as is typical of flying wing designs, and thus has a long range. Like the F-117A, it requires computer assistance to maintain stable flight. The B-2 has its origins in the Northrop YB-49 flying wing prototype of 1947, only one of which was produced.

The F-117A was withdrawn from service in the US Air Force in 2008, as it was replaced by the far superior F-22 (Fig.9).

Ben Rich, the head of Lockheed's "Skunk Works" which developed the F-117A, referred to Professor Ufimtsev's work

Fig.8(a): the US Northrop Grumman B-2 Spirit bomber, in service since 1997. Jack Northrop worked on the YB-49 and so was given special permission in his retirement to see the design of the B-2; he was overwhelmed with happiness.

Fig.8(b): the YB-49, in a sense the predecessor of the B-2.

Fig.9: the US F-22. It is a highly capable aircraft – possibly the stealthiest ever built – but the program was cancelled due to cost after just 195 of a planned 750 were built.

as "the Rosetta Stone breakthrough for stealth technology". He is also regarded as the "father of stealth".

He described how, when the F-117A was being developed, a precursor model was mounted on a pole for radar range testing. A test operator said that it wasn't on the pole yet as there was no detectable radar return. Then a bird landed on the model, and it could be detected. That gives an idea of the low radar signature of that aircraft.

The F-117A used simple faceted flat panels which reflect radar away from threat directions, but that left it somewhat visible in other directions. On the more advanced B-2, all surfaces are curved, so radar reflections are minimal in all directions. The B-2 also has superior aerodynamics due to the use of curved rather than flat surfaces.

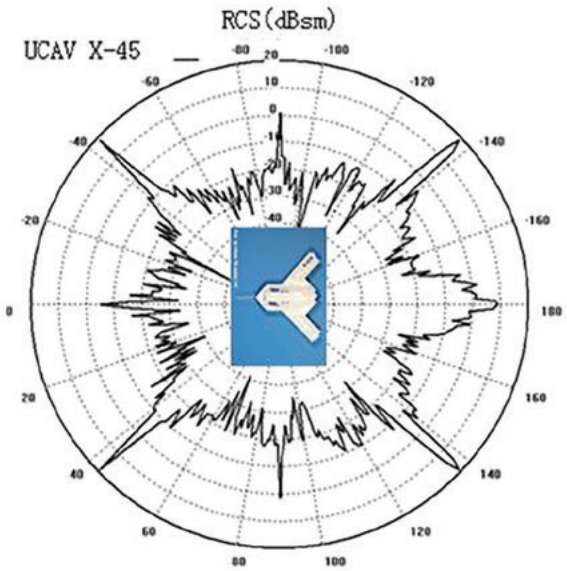


Fig.10: a calculated radar cross-section plot based on the published shape of a US X-45 drone, as presented by Chinese researchers at: siliconchip.com.au/link/aaz6 The actual RCS is classified, but this approximation demonstrates the effect of shaping on the radar return from various angles. Stealth design aims to reduce the spikes.

Radar cross-section

The radar cross-section (RCS) of an object can be minimised to reduce its visibility to radar. This is a measure of an object's reflectivity to the radar frequencies of interest.

The radar cross-section of an object is dependent up the following: the radar angle of incidence (object orientation), the size of the object, the geometry of the object and the radar frequency (different materials absorb or reflect radar differently at different frequencies).

The RCS is defined as the size of the projected area of a

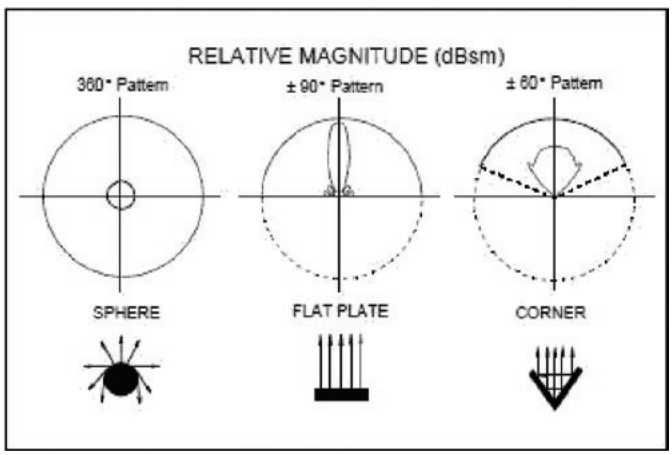


Fig.11: the radar cross-section of some basic shapes. Flat surfaces at right angles to the incoming radar signal are avoided in stealth designs and corners even more so. "Corner reflectors" are used when one wants to specifically make something visible to radar, such as a weather balloon.

Aircraft	Country	Type	Year	RCS (m^2)
B-52	USA	Bomber	1955	100-125
F-15 Eagle	USA	Fighter/bomber	1976	10-25
Su-27	USSR/Russia	Fighter/bomber	1984	10-15
F-4 Phantom	USA	Fighter	1960	6-10
F-16A Fighting Falcon	USA	Fighter	1978	5
Su-30MKI	Russia	Fighter/bomber	2002	4
MiG-21	USSR	Fighter	1959	3
F-16C Fighting Falcon	USA	Fighter	1978	1.2
Human	Various	Procrastinator	?	1
F-18C/D Hornet	USA	Fighter	1984	1-3
B-1B Lancer	USA	Bomber	1986	0.75-1
Rafale	France	Fighter	2001	0.1-class
F/A-18E/F Super Hornet	USA	Fighter/bomber	1999	0.1-class
Eurofighter Typhoon	UK/DE/IT/ES	Fighter	2003	0.1-class
F-16IN Super Viper	USA	Fighter	2011	0.1-class
B-2 Spirit	USA	Stealth bomber	1997	0.1 or less
F-117A Nighthawk	USA	Stealth bomber	1983	0.025 or less
Bird	Sky	Worm eater	?	0.01
SR-71 Blackbird and A-12	USA	Reconnaissance	1966	0.01
F-35 Lightning II	USA	Fighter/bomber	2006	0.0015-0.005
F-22 Raptor	USA	Fighter	2005	0.0001-0.0005
Insect	Swamp	Pest	?	0.00001

Table1: radar cross section (RCS) of various aircraft and creatures

sphere which would give an equivalent radar return to the object illuminated by the radar.

Table1 gives such figures for many modern military aircraft, taken from a public source (www.globalsecurity.org).

The RCS can be represented as a polar plot in which the strength of a radar reflection is plotted as a function of the incident angle of the radar beam (Fig.10).

Reducing radar cross-section

There are three main methods to reduce the RCS:

1) Reducing the number of surfaces capable of reflecting a radar beam back to the receiver, eg, having no surfaces at right angles to the incoming radar (see Figs.11-13).

For example, the turbine blades of jet engines which must be hidden from direct impingement by the radar beam as they are effectively flat surfaces facing in the direction of flight (Fig.14).

2) Where shaping by design is not possible, or susceptible surfaces responsible for a high radar return cannot be eliminated, they can be coated with radar absorbing materials (RAM).

3) Using electronic countermeasures to jam or fool enemy radar, such as by presenting an attractive decoy target to a radar-guided missile (see Fig.22).

There are also dedicated electronic countermeasures aircraft for this purpose such as Australia's EA-18G Growler electronic attack aircraft (see our article on the Avalon Airshow from May 2019, p15; siliconchip.com.au/Article/11612).

Tactics are also important, such as making sure that vulnerable angles of the aircraft with higher radar returns are not presented to the enemy. Poor tactics were responsible for the destruction of an F-117A, as described in the panel later.

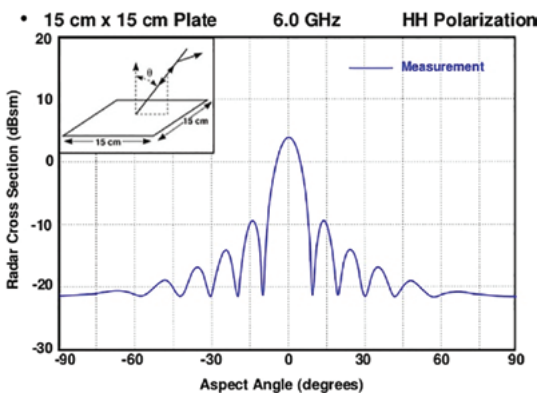


Fig.12: the RCS of a square plate 15x15cm as a function of the incident radar wave angle. The maximum reflection of ~4dB occurs at 0°, meaning that the 0.0225m^2 plate looks bigger at 0.0565m^2, while at an angle of 30°, the reflection is around -21dB, so the plate looks smaller, equivalent to 0.00018m^2. Image courtesy IEEE.

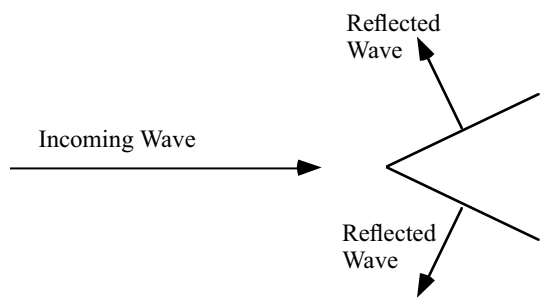
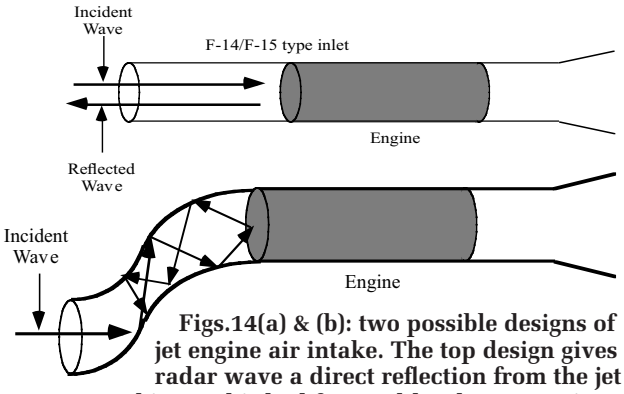


Fig.13: a basic shaping to reduce radar returns. It's designed so that the reflections are away from the incoming wave. Image source: W.H. Mason, "Fifteen Minutes of Stealth in Aircraft Design".



Figs.14(a) & (b): two possible designs of jet engine air intake. The top design gives a radar wave a direct reflection from the jet turbine and is bad for stealth. The serpentine design at the bottom is better, as the air inlet can be coated with radar absorbing materials to reduce the radar reflection. But the circuitous path is not the best for engine efficiency, and is difficult to model in the design stage. *Image source: W.H. Mason.*

Fig.15: a Lockheed Martin F-35 Lightning II stealth fighter in Australian livery.

Radar absorbing materials (RAM) and paint (RAP)

Reflected radar signal strength is directly proportional to the radar cross-section and inversely proportional to the fourth power of the distance, so if large amounts of radar energy can be absorbed, the detection range can be reduced.

It was suggested in "The Fundamentals of Fighter Design" by Ray Whitford (2000) that it would be of tactical significance to reduce the distance at which an enemy radar can detect a stealth aircraft to 18% of that for a non-stealth aircraft.

This requires a relative radar return strength of 0.18^4 = 0.001, meaning that a stealth aircraft must have an RCS 1000 times lower than a regular aircraft. So stealth treatments have to be highly effective to be tactically meaningful.

The purpose of RAM and RAP is to absorb radar or other radio energy of a specified frequency and dissipate it as heat. Ideally, these materials should be as broadband in their frequency response as possible, but there are practical limitations to this.

Other requirements include durability, low weight, minimal thickness, low cost (especially for large platforms such as ships) and ideally, the ability to easily adjust the material composition to suit different frequency requirements.

There are several types of radar absorbing materials. Note that plastic composites with non-conductive reinforcement such as Kevlar or fibreglass do not reflect radar signals anywhere near as much as metals. It is even possible to produce structural RAM, where the platform structure itself absorbs radar.

Dielectric RAM consists of electrically lossy filler particles, such as carbon black, in a foam, resin or rubber matrix. Certain fillers of the right dimensions can, in addition to electrical losses, produce a destructive interference effect. The RAM structure may consist of two or more layers with different properties, to achieve the desired broadband absorption.

Magnetic RAM is often in the form of paint which has magnetic spheres of ferrite or carbonyl iron embedded in an insulating matrix such as rubber or epoxy. Electromagnetic energy is lost in the ferrite or iron particles and energy is absorbed. This type of material is characterised by good bandwidth and absorption at reasonably low thickness. A disadvantage is that these materials are relatively heavy.

Such paints were used on the SR-71 and the F-117A.

In both magnetic and dielectric RAM, a continuous gradation of properties through the thickness of the material might also be used, such as a layer that has a small concentration of carbon or ferrite at the front and a much higher concentration at the rear.

Hybrid RAM may have a combination of magnetic and dielectric RAM to achieve a more broadband response and lesser thickness.

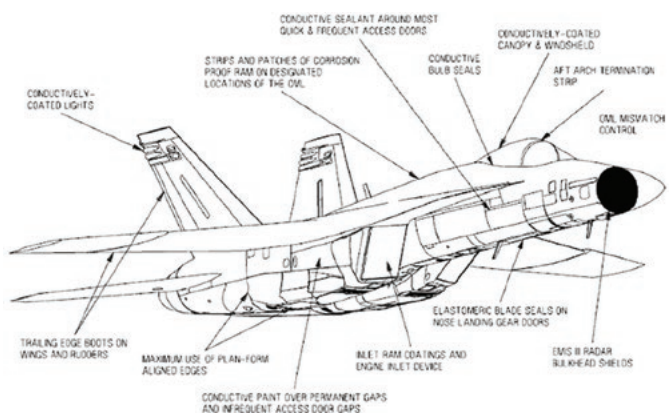

CONDUCTIVE SEALANT AROUND MOST QUICK & FREQUENT ACCESS DOORS
CONDUCTIVELY-COATED CANOPY & WINDSHIELD
STRIPS AND PATCHES OF CORROSION PROOF RAM ON DESIGNATED LOCATIONS OF THE OML
CONDUCTIVE BULB SEALS
AFT ARCH TERMINATION STRIP
CONDUCTIVELY-COATED LIGHTS
OML MISMATCH CONTROL
ELASTOMERIC BLADE SEALS ON NOSE LANDING GEAR DOORS
TRAILING EDGE BOOTS ON WINGS AND RUDDERS
MAXIMUM USE OF PLAN-FORM ALIGNED EDGES
INLET RAM COATINGS AND ENGINE INLET DEVICE
EMIS III RADAR BULKHEAD SHIELDS
CONDUCTIVE PAINT OVER PERMANENT GAPS AND INFREQUENT ACCESS DOOR GAPS

Fig.16: various treatments to reduce the radar cross-section of the F/A-18E/F Super Hornet. *Source: siliconchip.com.au/link/aaz7*

Fig.17: the Russian SU-57 fifth-generation stealth fighter.

Fig.18: the Chinese Chengdu J-20 fifth-generation stealth fighter.

Fig.19: the first known stealth helicopter, the Hughes 500P "Quiet One" in Laos during the Vietnam war.

A split-ring resonator can also be used. This is a type of metamaterial (see Fig.26).

A Salisbury Screen is a type of narrow-band dielectric absorber which consists of a resistive coating, a spacer of one quarter the wavelength to be absorbed and a metal backing plate. It is simple in concept but not generally used in stealth applications. A Jaumann absorber, first used in 1943, is a variation of this; it is like a multi-layer Salisbury Screen and can absorb two wavelengths.

Efforts are underway to develop RAMs with properties which can be changed dynamically to suit the required conditions. Note that RAMs can be used on certain civilian structures to reduce undesired reflections, such as the interference to radar systems caused by wind turbines.

Electronic emissions

These should be eliminated where possible. An aircraft whose own radar emissions can be picked up by passive sensors at long distances is not very stealthy; stealth aircraft generally have 'low probability of intercept' (LPI) radars. They are usually electronically-scanned phased-array types, as they can scan much faster than traditional radars.

Emissions shielding is also required around cockpit equipment, and gaps around access doors need to be electrically continuous to reduce the electronic noise leakage.

Fig.20: a comparison of a standard Black Hawk helicopter (as used by Australia) and the stealth version, which has an extra rear rotor blade, and the main rotor has down-turned tips. The stealth version is also much smoother, with fewer protuberances, plus angled sides which are likely made of or coated with radar absorbing materials.

Other stealth aircraft

The US Lockheed U-2 spy plane (operational in 1957) was thought to be untrackable with Soviet radar due to the altitude at which it flew (70,000ft). It is now known that the Soviets tracked every single flight, but they did not have an antiaircraft missile capability to shoot it down. That infamously changed in 1960 when one was shot down by an SA-2 missile

Attempts were made to reduce the plane's RCS under the auspices of the CIA's "Project RAINBOW". Techniques included "wallpaper" sheets with an electrically conductive printed circuit pattern (a type of metamaterial, see below) attached to the fuselage to absorb radar signals.

There was also a system of wires called the "trapeze" to reduce reflections from lower frequency 65-85MHz long-range radars. These were attached about 30cm from the wing leading and trailing edges, and other wires with precisely-placed ferrite beads designed to reduce the reflection from the fuselage and vertical stabiliser.

These measures were unpopular with pilots and also caused a fatal crash, which led to their abandonment in 1958.

The US aircraft which followed, explicitly designed to have low radar signatures, are the F-117A, B-2, F-22 and F-35 (Fig.15). Other aircraft, such as the F/A-18E/F, have been modified to reduce their signature (Fig.16), but are not purpose-built "stealth aircraft". The A-12 and SR-71 mentioned above had certain stealth design elements but were not fully designed for stealth.

The Russian SU-57 (Fig.17) is a stealthy fifth-generation fighter like the F-35, as is the Chinese J-20 (Fig.18).

Australia also has a stealthy UCAV (unmanned combat aerial vehicle) under development. It is the Boeing "Loyal Wingman" which was described on page 13 of our May 2019 issue (**siliconchip.com.au/Article/11612**). It is expected to fly sometime this year. See the video *"Boeing Airpower Teaming System: A smart unmanned team for global forces"* at **siliconchip.com.au/link/aazc**

Stealth helicopters

Helicopters are intrinsically difficult to make stealthy because of the shape of the rotor blades, tail rotor and control

Fig.21: a Revell plastic model of the Russian Kamov Ka-58 stealth helicopter. The model was based on information accidentally released by the Russians in October 2018.

Fig.22: the Australian-developed Nulka decoy; Australia's largest defence export, worth $1 billion in export revenue. It is more effective if the radar signature of the ship it is protecting is minimised, so the Nulka presents a larger target.

gear. These present a large and constantly changing variety of angles for radar to reflect from, plus a substantial acoustic signature.

Nevertheless, helicopters are a valuable military asset and it is worth making an effort to reduce their signature. The existence of stealth helicopters mostly came into public knowledge with their use in the raid on Osama bin Laden.

The first known stealth helicopter was a modified Hughes 500 or OH-6A called the 500P (Fig.19) where "P" was for penetrator. The CIA used this during the Vietnam War. It was designed for acoustic stealth rather than radar or visual/infrared stealth, and it was known as "The Quiet One".

Research started as early as 1968, and it was built to perform one specific covert operation in December 1972, which was to tap into a phone line deep inside enemy territory to see if the North Vietnamese were adhering to peace terms.

The tail rotor was determined to be one of the chief sources of noise. By doubling the number of blades, the speed of the rotor was halved, reducing noise dramatically. Additional modifications included an extra main rotor blade for a total of five, alterations to the blade tips, an engine exhaust muffler and lead pads to reduce vibrations from the aircraft skin.

The distinctive "chop, chop, chop" noise of helicopters arises from the main rotor blade creating vortices at the blade tips, which are subsequently struck by the following blade. The blade tip modifications minimised this, and the extra blade allowed the main rotor speed to be reduced. The helicopters weren't silent, but they produced less of the type of noises that most people would notice.

Tests were conducted at the famous Area 51 in Nevada. Don Stephens, who managed the Quiet One's secret base in Laos for the CIA said "It was absolutely amazing just how quiet those copters were. I'd stand on the [landing pad] and try to figure out the first time I could hear it and which direction it was coming from. I couldn't place it until it was one or two hundred yards away."

Rod Taylor, who served as the project engineer for Hughes, said: "There is no helicopter today that is as quiet." At least one of these helicopters is still in service today with a private company. See the video *"Former NOH-6P Quiet One – Startup"* at **http://siliconchip.com.au/link/aazd**

The Sikorsky UH-60 Black Hawk is a US military helicopter (also used by Australia) and a (then) secret stealth version was used in the 2011 raid on Osama bin Laden in Pakistan. It was reported that it had extra blades on the tail rotor as a noise reduction measure, and various surface features and materials consistent with stealth technology (Fig.20).

The Russians also have a stealth helicopter, the Kamov Ka-58 (Fig.21). The Russians accidentally disclosed its existence in October 2018.

Stealth ships

It is vital to manage the radar, infrared and other signatures of ships. One objective in reducing the RCS of a ship

Fig.23: the USS Zumwalt stealth ship. It needs to use reflectors to make it visible to maritime radar to avoid collisions. The program was cancelled due to the huge expense.

Fig.24: the stealthy Lockheed Martin LRASM Long Range Anti-Ship Missile.

Fig.25: F-35 stealth fighters launching low observable JSMs.

is making a decoy such as the Australian developed Nulka (Fig.22) a more attractive target for missiles.

The Nulka is a hovering rocket which is launched from a ship when a hostile missile is detected, to lure anti-ship missiles away from their intended target. It is in use by Australia, Canada and the USA. It was successfully used in combat, when US ships off the Yemeni coast came under enemy missile fire.

The USA produced a stealth ship in the form of the Zumwalt class (Fig.23), but the program was cancelled due to high costs. See the video *"Zumwalt - destroyer from the future"* at **siliconchip.com.au/link/aaze**

Other navies have stealth ships, mostly experimental, with a few in service. It is possible to retrofit existing ships to reduce their signature, such as with the fitment of RAMs or the retrofitting of a simpler mast design with fewer reflecting surfaces.

Australia's CSIRO is developing smaller, stealthier antennas for Navy ships. To quote them, "We're looking to replace these with a small number of radio frequency antennas that are much more sensitive, lightweight, low-noise and as small as a Coca Cola can. The new technology aims to give the Navy greater stealth, safety, new functionality and cost savings."

Stealth missiles

The main defence a ship has against a missile which gets close enough to 'lock on' to it is to shoot the incoming missing down using a close-in weapons system (CIWS). A stealthy anti-ship missile is harder to defeat with a CIWS.

The USA has developed a stealth anti-ship missile which has artificial intelligence, called the AGM-158C Long Range Anti-Ship Missile (LRASM) – see Fig.24 and the video at **siliconchip.com.au/link/aazf**

The Joint Strike Missile (JSM), designed for use with the F-35 and other platforms, is also stealthy (Fig.25). It can be used against land and sea targets. Australia will use this missile and is funding the development of a new passive RF seeker for it, allowing it to locate targets based upon their "electronic signature" (the precise meaning of which is not specified) rather than radar or infrared signatures.

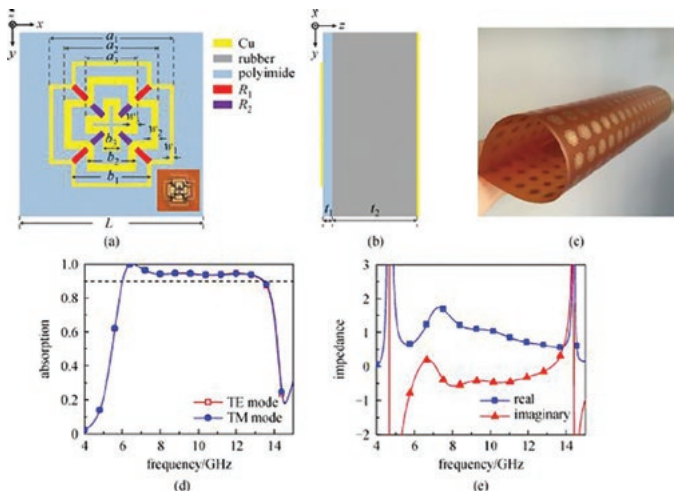


Fig.26: this split-ring resonator can be considered a resonant structure with some resistive elements. The structure is rubber with a polyimide coating on one side and copper on both sides. a1 = 9mm, t1 = 0.18mm, t2 = 3.5mm, R1 = 270Ω and R2 = 150Ω. TE is transverse electric and TM is transverse magnetic. *Image source:* siliconchip.com.au/link/aaz8

Fig.27: a Chinese GJ-11 Unmanned Combat Aerial Vehicle showing various stealth characteristics, including a shrouded exhaust to minimise infrared signature, blended wings, smooth shape, low overall profile and a flying wing design with no fuselage or tail fins. The result is a low radar signature. It has been suggested that this is not a real flying aircraft but a mockup.

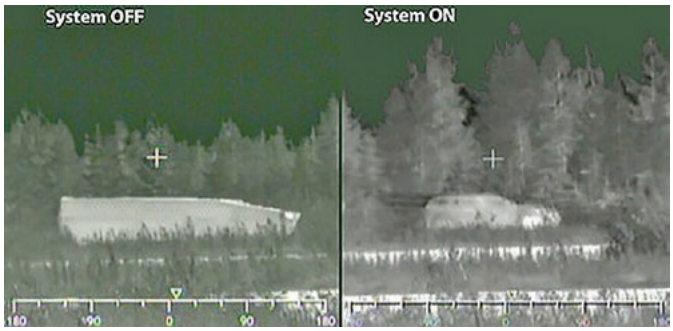


Fig.28: Adaptiv infrared stealth technology on an armoured vehicle with the system off and on. Panels are heated or cooled to give the appearance of a car when viewed with infrared imaging equipment.

This work is being carried out by BAE Systems Australia and Kongsberg Defence.

Metamaterials

Metamaterials are materials whose properties derive from their structure rather than the properties of the individual materials from which they are made. Structural elements typically include repeating patterns of specific shapes, sizes and orientation (Fig.26). Properties can be achieved that differ from the bulk properties of the material from which they are made.

For materials designed for electromagnetic applications, typically the structural elements have feature sizes smaller than the wavelength they are intended to interact with. For radar absorbing material applications, properties can be achieved such as broadband absorption or the ability to redirect the reflection of incoming radiation away from the source without specific surface shaping.

Metamaterials can also have favourable properties for applications such as acoustic absorbers in submarine hulls (see below).

Infrared stealth

Apart from reducing the RCS, it is also crucial to reduce a platform's infrared signature. For an aircraft, ship or armoured vehicle, the exhaust is the main source of infrared emissions. On an aircraft, this can be reduced by extensions around the nozzles to hide them from view at the angles that are to be most protected (Fig.27).

Cold air can also be mixed with the hot exhaust gases to lower the signature.

It is also desirable to reduce the infrared signature of the platform itself. This can be done by ensuring that there are no hot surfaces and also by using highly reflective paint to ensure a minimum of heating by the sun. Unfortunately, many materials that reflect infrared (desired) also reflect radar (not desired).

As with radar jamming, there are devices that emit infrared pulses to fool infrared seekers of missiles. Another common infrared heat-seeking missile countermeasure is to release flares, which may cause the missile to lock onto the wrong target.

Adaptiv is an infrared active camouflage system by BAE

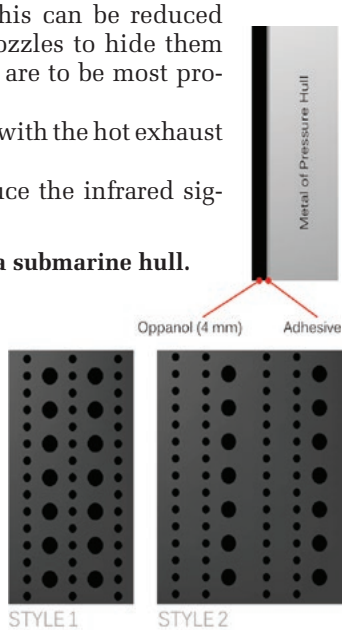
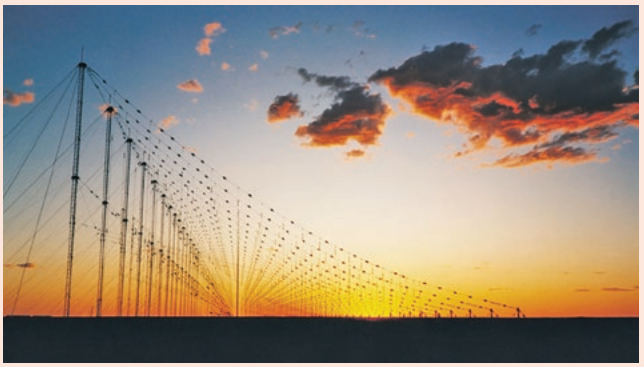


Fig.29: acoustic coatings for a submarine hull. They are typically made of a rubber-like material with holes containing air or solid inclusions of different properties on the hull side, while being smooth on the outside. The holes or inclusions scatter and absorb acoustic energy. These are "Alberich" tiles as used by Germany during WWII. *Image credit: Wikipedia user NZSnowman.*

Fig.30: acoustic tiles on a modern submarine; some that have fallen off due to defective adhesion. There is also what appears to be a vent. Adhesion of tiles to the hull is a problem; the tiles are relatively thick, heavy and expensive. Research aims to minimise these characteristics.

The Jindalee Operational Radar Network (JORN)



JORN is an Australian over-the-horizon radar system used to defend Australia. It can detect aircraft and surface vessels at least 2000km from the mainland.

It allegedly can detect stealthy aircraft because it operates in the HF frequency band of 5-30MHz, while stealth aircraft are typically designed to avoid detection in the microwave spectrum (see siliconchip.com.au/link/aaz4).

Also, because it is an over-the-horizon system and the radar beam bounces of the ionosphere, the beam will strike aircraft from the top, which will have a higher radar reflectivity due to its flatness. Stealth aircraft designs are typically optimised for cases where the radar beam comes from a low angle (from a surface radar) or on the same plane (from other aircraft at a similar altitude).

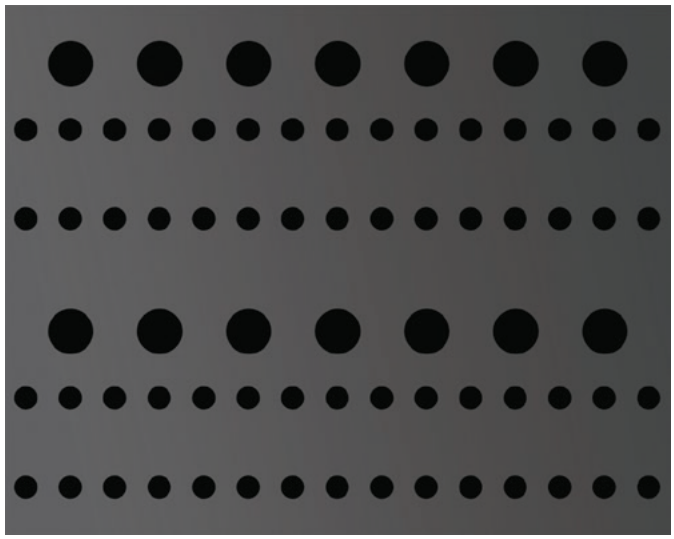


Fig.31: a clearer view of the repeating void/inclusion pattern within the German acoustic tiles.

Systems which variously heats or cools special panels on a vehicle to make it blend in with the background or appear something that it is not, such as a car (see Fig.28).

Visual signature

Visual signatures can be minimised by paint or camouflage schemes that blend in with the background, or to make the vehicle appear to be something that it's not or to appear in a different orientation, such as painting a fake canopy on the underside of an aircraft.

Aircraft and rocket engines also produce contrails or smoke under certain conditions, which can give away their position. Contrails can be minimised to some extent by special fuel additives or by flying the aircraft at an altitude where atmospheric conditions won't produce them. Smoke can be reduced by using smokeless rocket fuel.

Stealth submarines

There are two main aspects of stealth concerning submarines: acoustic and radar.

Acoustic stealth is designed to both minimise echoes reflected back to hostile active (search) sonar, plus reduce internally-generated sounds so they can't be heard by passive (listening) sonar. The frequency response of the stealth system, usually hull-mounted tiles (Fig.29 – 31), should ideally be effective at all expected frequencies of sonar and internally generated noise.

Fig.33: the Fibrotex mobile multispectral camouflage system

Fig.32: a demonstration of the HyperStealth Quantum Stealth technology. Despite the name, there is no quantum mechanical effect involved.

Radar stealth is intended to minimise radar reflections from a submarine when it is surfaced, raises its periscope or uses its snorkel to ingest air for breathing or for diesel

The F-117A shootdown

In 1999, a US F-117A stealth aircraft was shot down by enemy forces in Yugoslavia. This came as a shock to the world, but it wasn't due to a deficiency in the aircraft stealth system, but rather poor tactics.

No platform is ever completely invisible to radar or other electromagnetic radiation, so the best tactic is to present to the enemy the angles of a platform that are least visible to radar (or infrared imaging system, etc).

In this case, the aircraft flew the same path on its bombing runs every night. Also, electronic countermeasures aircraft did not accompany the F-117A as was proper practice.

The most radar-reflective part of the F-117A was the flat underbelly; thus, pilots were trained not to perform banking turns in enemy airspace. The enemy was aware of the presence of this aircraft and had occasional radar returns, but not enough for a target lock.

So one day, they moved their radar directly beneath the known nightly flight path, got a lock onto the target and shot it down. Some say lock was made when it had its bomb bay doors open, providing a higher radar signature.

The wreckage was sold to the Russians and Chinese. The pilot was rescued but came close to capture.

The F-117A is now regarded as obsolete technology, and was withdrawn from service in 2008.

Fig.34: the Army's Australian Multicam Camouflage Uniform (AMCU). The pattern and colours are designed to blend into the background.

engines (not necessary for nuclear submarines). Radar absorbing coatings were first used on U-boats during WWII (along with acoustic tiles).

Noise generated by submarines is minimised by careful attention to hull design to ensure a minimum of noise-generating turbulence, plus particular attention to the propeller or propulsor design such as a pump jet. Also, internal equipment noise from devices such as pumps, fans and motors is minimised via noise and vibration-isolating mountings.

Australia's current Collins-class submarines had several noise problems when new; the solutions are documented at siliconchip.com.au/link/aazg

Hopefully, lessons have been learned, and the problems and their causes are not repeated in the new submarines under procurement.

Acoustic tiles can serve either an anechoic function (reducing the strength of reflected sonar waves) or a decoupling function (reducing the amount of internal submarine noise radiated to the outside). Ideally, a single tile system will perform both functions. Rubber tiles typically have holes or inclusions designed to scatter acoustic energy, or eliminate it by destructive interference.

The latest development in tile technology is materials known as acoustic metamaterials, and a particular design known as a phononic crystal.

Phononic crystals have a bandgap much like the bandgap in semiconductor materials, so they absorb sound over the designed frequency range. In Australia, such research is underway by the UNSW School of Mechanical and Manufacturing Engineering.

Variation of the acoustic performance of tiles with depth must be considered, as hollow cavities may be compressed due to pressure, altering the dimensions and therefore the frequency response.

Other approaches to acoustic energy management with a submarine are outlined in US Patents US5220535A "Sonar baffles" and US4450544A "Absorptive sonar baffle". However, these appear not to be known to be in service.

Other methods that can be used to find submarines and which need to be managed for stealth purposes include:

- magnetic anomaly detection, where distortions in the Earth's magnetic field caused by a submarine are detected.

Fig.35: a ghillie or yowie suit for optical stealth. The shoes are generally hidden behind the wearer's body.

- infrared detection of surfaced submarine.
- a trail of warm water left by a submarine's cooling system (especially nuclear subs).
- detection of pressure waves from a submarine.
- detection via satellite of the surface wake created by a submerged submarine.
- detection of bioluminescence caused by the excitation by a submarine of organisms such as dinoflagellates.

HyperStealth "Quantum Stealth" material

HyperStealth Biotechnology Corp (siliconchip.com.au/link/aazh) is a Canadian camouflage design company. They developed a "Quantum Stealth" optical stealth material that is as thin as paper, passive, cheap and bends light around an object to make it appear invisible or at least highly obscured under the right circumstances (Fig.32).

It uses one or more lenticular lenses, which you can sometimes buy cheaply on eBay if you want to experiment yourself. A lenticular lens is usually in the form of a flat sheet with a series of parallel long convex lenses running along its length. They are the basis of stickers and cards in which the image appears to move when you move the card or your perspective.

The HyperStealth material essentially disguises the object behind by stretching and bringing together the images from

Australian stealth materials capability

Australia has the capability to research and manufacture materials for radar stealth.

See the video *"Radar Absorbing Materials for Australian Defence Platforms, by Dr Andrew Amiet"* at siliconchip.com.au/link/aazi

Australia can also design and manufacture anechoic tiles for submarines. In both cases, materials are optimised for Australian conditions such as warm weather and water. Both research activities occur through the Defence Science and Technology Group (DST).

Supersonic anti-ship missiles – not very stealthy!

One of the advantages of a ship with a low radar signature is that it is less visible to anti-ship missiles that typically have active radar homing during the terminal phase. Other missiles use infrared homing, so a low infrared signature is important as well.

More advanced missiles also can home in on a ship's "electronic signature"; for example, the JSM mentioned above which has an RF sensor under development in Australia.

As mentioned earlier, ships rely on close-in weapons system (CIWS) to destroy incoming missiles. A supersonic missile gives the CIWS less time to react before it hits the ship. There is current controversy since Russia and China have supersonic anti-ship cruise missiles and the United States and allies only have relatively few in service.

There are several reasons for this. Faster missiles tend to fly at higher altitudes where the air is thinner, making them visible from a greater distance as compared to a sea-skimming subsonic missile.

A missile flying at 10m above the surface can be detected at 31km with a radar 20m above the surface, but a Russian Kh-32 missile with a speed of at least Mach 4.1 flies at 40,000m altitude and could theoretically be detected at a range of 843km away. This means longer-range anti-missile missiles could engage it before coming into range of the CIWS.

So a slower, lower flying missile is only detectable much later than a faster, higher-flying one. Therefore, faster missiles are not necessarily better.

For more details, see the video *"Why Does the US Not Have Supersonic ASMs? (Anti-Ship Missiles)"* at **siliconchip.com.au/link/aazj**

either side of it. The object has to be at a certain distance behind the invisibility screen for this to work.

This product has been promoted to various military organisations, but it is not clear what practical use it would have.

See the video *"Hyperstealth Invisibility Cloak 9 Minute Promotional Video"* at **siliconchip.com.au/link/aazk** and also *"Quantum Stealth (Invisibility Cloak) Edited 49 Minute Technical Edition"* at **siliconchip.com.au/link/aazl**

There is also an independent video production titled *"How this 'invisibility cloak' material is made and how it works"* at **siliconchip.com.au/link/aazm**

Fibrotex

Fibrotex (**siliconchip.com.au/link/aazn**) is an Israeli company that makes a variety of signature management products, including the mobile multi-spectral camouflage system (Fig.33), intended to be quickly applied to vehicles to reduce their signature in the optical, infrared and radar frequencies. See the video *"Mobile Camouflage – Fibrotex"* at **siliconchip.com.au/link/aazo**

Stealth clothing

The most basic and ancient method of stealth is through visual camouflage. Camouflage to blend in with the background is extensively used by animals. Similarly, people can wear colours and patterns that blend in with the background.

The current standard Australian military camouflage uniform since 2014 is the Australian MultiCam Camouflage Uniform (AMCU) – see Fig.34. The pattern is based on the US-developed Crye Precision MultiCam with a colour palette derived from the previously used Australian Disruptive Pattern Camouflage Uniform (DPCU, also known as Auscam or jelly bean camo).

The AMCU was designed by Defence Science and Technology Group and is intended to work in all areas of Australia and the immediate region. It uses a total of six colours and also takes into account its near infra-red signature. There is a variant for the Navy known as the Marine Multi-cam Pattern Uniform (MMPU).

According to the developer of the MultiCam pattern, it works by taking advantage of the way a person perceives shape, volume and colour with the brain doing a lot of "filling in" for the eye. This effect is exploited to trick the brain into seeing the MultiCam pattern as part of the background, rather than as a distinct object.

A ghillie suit (or yowie suit as it is known in the Australian Army – see Fig.35) is a type of optical stealth clothing often worn by military snipers (but also by wildlife photographers and hunters). It is designed to blend in with a particular environment. Such suits are hand-made, often by the snipers themselves. They are effective but can be hot and heavy.

Military clothing is usually designed for relatively low optical visibility in its intended operating environment, but maintaining low visibility to radar and infrared is also increasingly important. This requires so-called multispectral camouflage.

NIR compliance refers to clothing and vehicles that have been treated to make them less visible in the near-infrared (NIR), making them less visible to night vision devices (NVDs). These typically operate in the visible and near-infrared range (wavelengths of 0.4-1.0µm) while thermal infrared imaging cameras typically operate in the range of 3-12µm (see Fig.36). So NIR compliance does not give protection against thermal imaging systems.

The Russian Ratnik combat clothing, as well as the military uniforms of some other countries, is made of materials that render it less visible to infrared imaging systems.

In 2013, Artist Adam Harvey developed a line of street clothing which renders the wearer less visible to the thermal infrared cameras of surveillance drones. The items were said to be made from silver-plated fabric which reflected thermal radiation. They do not seem to be available at the moment. See **siliconchip.com.au/link/aazp**

Fig.36: this Phoenix-H Handheld Thermal Imaging Surveillance Sight can spot vehicles with unsuppressed infrared signatures at up to 11km or people up to 6km. It operates in the 3µm-5µm range.

New B-21 “Raider” stealth bomber details revealed

The US Air Force has been working on a new long-range conventional/nuclear stealth bomber for some time now. It will be known as the B-21 Raider, with a planned first flight in December 2021.

It will re-use some existing technology and parts, such as the engines from the F-35 stealth fighter; the idea is to use established technology where applicable rather than developing new technologies. It will also use an “open architecture” with its electronics and software, making it much easier and cheaper to upgrade, to cope with new operational conditions and new requirements.

All these features will supposedly help keep costs down, with an estimated cost of around US$550 million per aircraft (in 2010 dollars). That is about half the cost of the B-2 bomber it is intended to replace, and only about 30% more than a wide-body commercial jet like the Boeing 777-9.

The Northrop Grumman B-21 will join the current heavy bomber fleet which consists of Boeing B-52s (entered service in 1955, planned retirement in 2050), the Rockwell B-1B (entered service in 1985, planned retirement in 2036) and Northrop Grumman B-2 (entered service in 1993).

It will supposedly be able to “destroy any target, anywhere”, including deeply buried targets. It will ultimately replace the B-2 in the strategic nuclear role, and the B-1B for conventional bombing.

The B-21 will also have the capability to operate without external communications, which might be unavailable during wartime due to jamming or nuclear strikes. Their use might also reveal the location of the aircraft.

The B-21 is designed with low maintenance requirements. The B-2 bomber requires a lot of maintenance, primarily due to its stealth coatings.

One design requirement for the B-21 was that it should be as easy to maintain as a conventional F-15 fighter jet.

The B-21 is similar to the original B-2 bomber concept, before its design was altered late in its development. The B-2 was initially conceived as a high-altitude bomber, but it was later decided that it needed low-altitude flight capability to evade the then-newly developed Soviet radars.

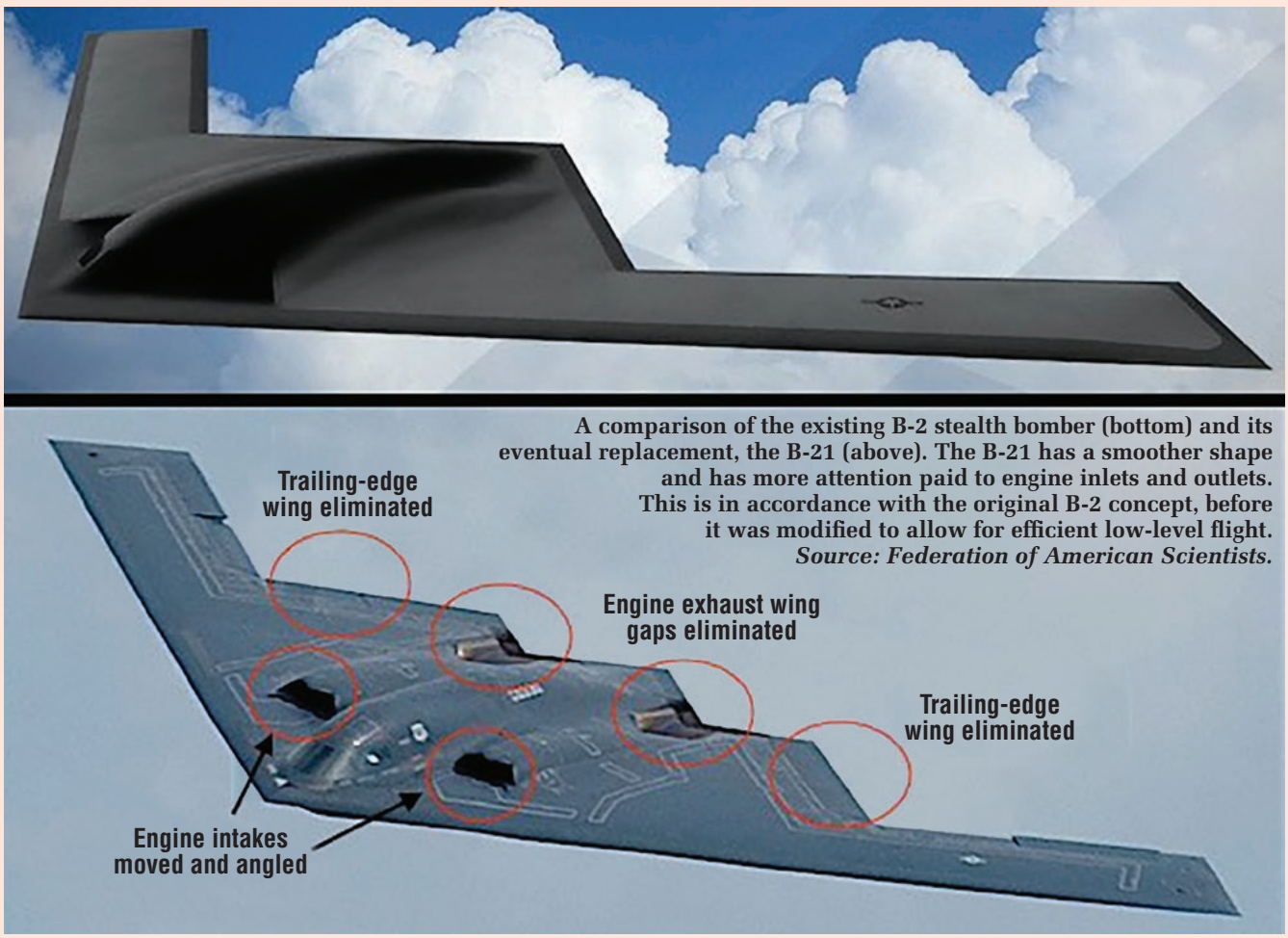
This caused a reduction in range and payload, and resulted in a larger radar cross-section (RCS).

The B-21 is also designed to be more stealthy in the lower-frequency VHF and UHF bands; increasingly, radar systems are designed to operate at these frequencies to detect stealth aircraft (which are typically designed to evade higher-frequency radar).

The B-21 will supposedly be so invisible to radar at typical illumination angles that it will blend in with the background noise, even in the VHF and UHF bands.

To achieve stealth at lower frequencies from shaping alone, geometric aircraft features have to be longer than the wavelength of the radar, or else electrical resonance occurs, resulting in a strong signal return.

Radar absorbing materials to deal with such low frequencies would have to be of an impractical thickness, for example, as much as 60cm thick. SC


Trailing-edge wing eliminated
Engine exhaust wing gaps eliminated
Trailing-edge wing eliminated
Engine intakes moved and angled

A comparison of the existing B-2 stealth bomber (bottom) and its eventual replacement, the B-21 (above). The B-21 has a smoother shape and has more attention paid to engine inlets and outlets. This is in accordance with the original B-2 concept, before it was modified to allow for efficient low-level flight. ***Source: Federation of American Scientists.***

Anodising Aluminium at home

Many aluminium products, such as heatsinks, are available pre-anodised, with a hard coating of aluminium oxide (often dyed black) that makes the surface considerably tougher. But sometimes parts are supplied in 'raw' aluminium. What if you'd like *them* anodised? As it turns out, as long as you take due care (especially with the chemicals used), it isn't that hard to do it yourself.

by Phil Prosser

We are all familiar with aluminium. It is a very common metal that is seen in all aspects of our lives, from structures through to household goods like drink cans and of course in electronic systems.

After all, aluminium is the most abundant metallic element in the Earth's crust.

Aluminium was not isolated as a metal by itself until 1824, and not industrially produced until the mid-1800s. The primary difficulty was that efficient refinement of aluminium ore to metal requires electrolys at very high temperatures and uses a great deal of electrical energy, which was not available back then.

So common industrial use of aluminium did not commence until well into the 1900s. Read up on the Hall–Héroult process if you are interested.

Why anodise?

As hobbyists, aluminium is a 'go-to' material due to its easy workability, ductility, low weight and low cost.

But it is often not clear how to finish the aluminium that you use. Many commercial products have an anodised finish, which is easily recognised by the very thin, very hard and often coloured finish.

The principal benefit of anodising aluminium is that it significantly increases the corrosion resistance of the underlying metal.

When you cut or otherwise expose raw aluminium, it very quickly oxidises and forms a layer of aluminium oxide (Al_2O_3) on the surface. This actually forms part of the surface and is effective protection for the underlying reactive material.

Still, it is very thin, easily damaged and is not sufficient to protect the metal in corrosive environments or over long periods.

For industrial applications, aluminium surface protection cannot be left to chance. The anodising process is often used to artificially grow a thick layer of aluminium oxide on the metal surface.

This provides excellent corrosion resistance and provides an extremely hard protective layer to the metal.

The structure of aluminium oxide in the anodised layer also provides the ability to bind dyes, which is how many anodised surfaces are coloured

Doing it yourself

In this article, I will describe how you can anodise and dye your own parts at home, resulting in much more durable and attractive products.

For feature parts and modestly-sized items, anodising at home is a practical option. Very attractive results can be achieved without undue effort.

Some specialised applications require "hard anodisation" which creates a thick, hard oxide layer aimed at providing wear resistance.

Standard anodisation creates an oxide layer up to 30 microns thick, while hard anodisation can create a layer up to 100 microns.

But this involves refrigeration and much higher voltages; while you probably could do it at home, it isn't as easy. So I won't describe that here.

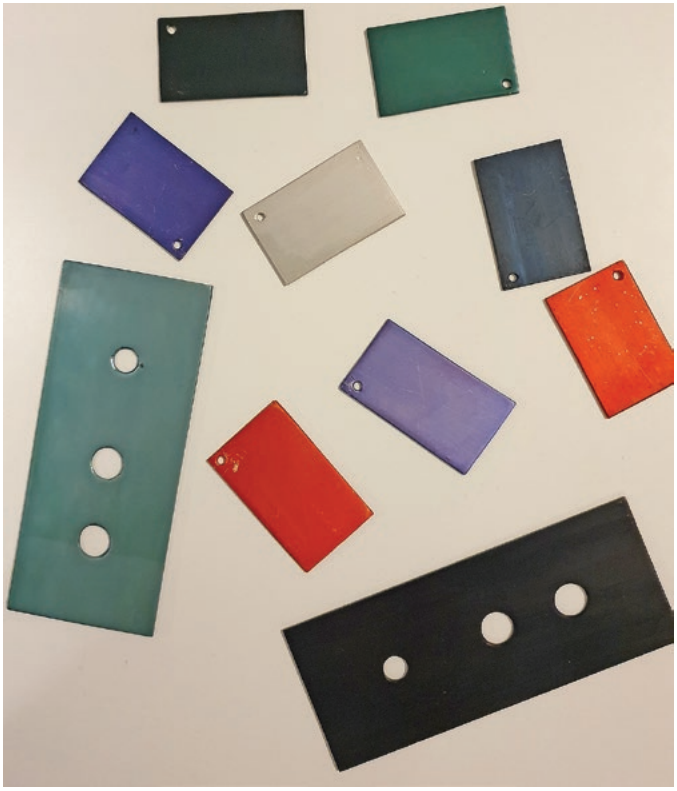
So the goal of this article is to describe the regular anodisation process, which provides corrosion resistance and the ability to apply decorative finishes.

What can I anodise?

It isn't just aluminium that can be anodised. Other suitable metals include magnesium, titanium, tantalum and zinc.

But we'll focus here on aluminium as it is commonly available, easy to work and the process for anodising it is not complicated.

As you will see in this article, anodising falls somewhere between DIY electronics and chemistry. I will walk you through the following five steps:



- **Cleaning**
- **Pre-anodisation etching**
- **Anodising**
- **Dyeing**
- **Sealing**

We will also walk through the set-up of the etching bath, anodising bath and provide some guidance on how much

Here's what you will need:

Item	Source	Comment
Safety glasses	Any hardware store	*Buy a pair that wraps around your face.*
Nitrile gloves	Hardware store, supermarket	*Buy a large box of disposable gloves.*
Power Supply	Your workshop	*Ideally 3-30V at 1-6A (depending on job size).*
Clip leads	Your workshop	*Acid will corrode your clips! Wash them or use old leads.*
Anodising tank	Hardware store, supermarket	*A plastic tank just large enough to hold your workpieces – food containers or plastic pails are suitable.*
Lead Sheet	Hardware store	*This is sold as lead flashing. It is expensive.*
Sulfuric acid (H_2SO_4)	Battery or car accessory shops	*Acid is not on the shelf; you need to talk to staff. Expect to pay about $10/L.*
Sodium bisulphate ($NaHSO_4$)	Hardware store or pool shop	*Alternative to sulfuric acid; commonly sold as pool pH dropper.*
Safety container		*Slightly larger than your acid bottle, to contain any leaks.*
Rinsing container		*Larger than your parts, kept full of clean water for rinsing off after etching, anodising and staining.*
Dyes	Lincraft, eBay	*Clothes dyes or anodising dyes.*
Sodium bicarbonate	Supermarket	*1kg containers are cheap; buy several and keep at hand in case you need it to neutralise spilled acid. Also called "bicarb soda".*
Acetone	Hardware store	*Used for cleaning oil off parts before etching.*
Deionised/distilled water	Supermarket, car accessory shops	*Tap water can be used, but this is better.*
TIG aluminium wire	Hardware store	*Or strip out of cabling.*

We cannot emphasise enough the need for safety equipment and all care. Some of the chemicals used for anodising are pretty nasty and can cause damage or injury if you're not careful. You should also store chemicals with a second container which will catch any spills before they have a chance to do damage (known as "bunding", as seen at right).

current you should be using to anodise your parts and for how long.

Safety

Before we start, let's discuss safety. Anodising requires the use of both a strong acid and a strong base. It is essential to understand the hazards of working with these chemicals, and to know how to manage the risks involved.

Anodising aluminium uses two common but nevertheless nasty chemicals, sulfuric acid and sodium hydroxide.

Sulfuric acid is a hazardous chemical. In the concentrations we need, it is corrosive to eyes, respiratory system and skin. It will quickly eat through clothing and unprotected surfaces. You can download a PDF material safety data sheet (MSDS) from **siliconchip.com.au/link/ab0h**

The etching process uses a 2% mixture of sodium hydroxide, which is a caustic base, and quite harmful to skin and eyes. Download a PDF of its MSDS from **siliconchip.com.au/link/ab0i**

I recommend that you use the "take 5" approach before any operation using the chemicals in this article:

1) STOP before starting each activity. Consider all aspects of this, including your preparedness.

2) THINK through what you need to achieve and consider what might go wrong or cause a problem.

3) IDENTIFY potential hazards to yourself, others and the environment around you. What is the potential risk?

4) PLAN how to undertake the activity while minimising hazards. Have contingencies for spills etc.

5) PROCEED

So why do we need acid?

It turns out that sulfuric acid is an extremely useful reagent and a chemical that is found in many industrial processes and parts of everyday life. It is produced and used in large quantities all around the world. While sulfuric acid has primarily industrial uses, it's also found in everyday household products such as drain cleaner and fertiliser.

You should obtain and read the safety data sheets (linked above) for sulfuric acid, sodium hydroxide and, if you use it, sodium bisulphate (**siliconchip.com.au/link/ab0j**) before starting. Without seeking to replicate the safety data sheets, key messages are:

- **skin contact** – if sulfuric acid comes into contact with your skin, immediately flush the affected area gently with lukewarm water for at least 30 uninterrupted minutes. **Seek medical attention immediately**.
- **eye contact** – if sulfuric acid gets into your eyes, immediately flush the eye(s) with water for at least 30 minutes. **Seek medical attention immediately.**
- **ingestion** – if you ingest sulfuric acid, rinse your mouth immediately with water. Do not induce

Bicarbonate of Soda (often abbreviated to simply Bicarb Soda) is readily available in supermarkets as it is used extensively in cooking.

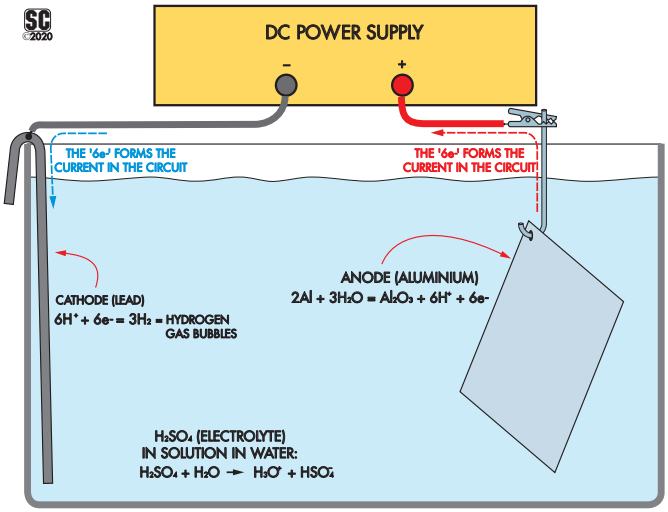

DC POWER SUPPLY
–
+
THE '6e-' FORMS THE CURRENT IN THE CIRCUIT
THE '6e-' FORMS THE CURRENT IN THE CIRCUIT
CATHODE (LEAD)
6H+ + 6e- = 3H2 = HYDROGEN GAS BUBBLES
ANODE (ALUMINIUM)
2Al + 3H2O = Al2O3 + 6H+ + 6e-
H2SO4 (ELECTROLYTE) IN SOLUTION IN WATER:
H2SO4 + H2O → H3O+ + HSO4-

Fig.1: the basic arrangement for anodising aluminium. The part to be anodised connects to the power supply +, while the lead cathode connects to the power supply –.

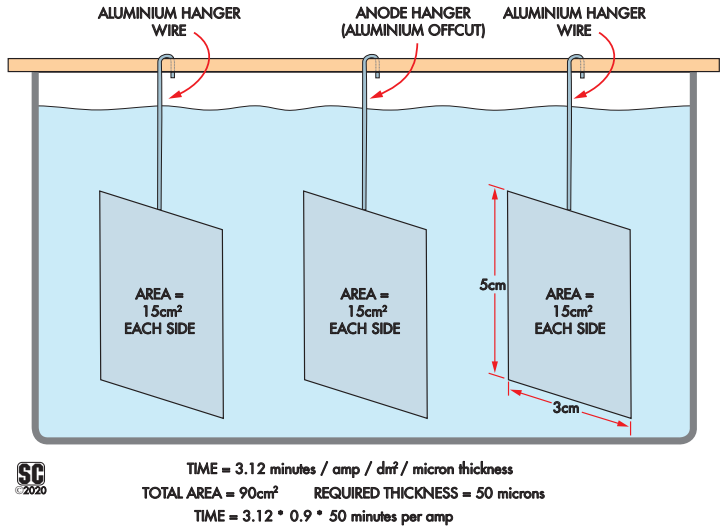

ALUMINIUM HANGER WIRE
ANODE HANGER (ALUMINIUM OFFCUT)
ALUMINIUM HANGER WIRE
AREA = 15cm² EACH SIDE
AREA = 15cm² EACH SIDE
5cm
AREA = 15cm² EACH SIDE
3cm
TIME = 3.12 minutes / amp / dm² / micron thickness
TOTAL AREA = 90cm² REQUIRED THICKNESS = 50 microns
TIME = 3.12 * 0.9 * 50 minutes per amp

Fig.2: you can anodise several pieces at once like this. Add up the total surface area (include both sides!) to calculate the required time and current.

vomiting. Continually rinse your mouth with water and **seek medical attention as soon as possible.**

- **inhalation** – if you inhale sulfuric acid aerosols, **seek fresh air and medical attention immediately.**
- **spills** – if you spill acid, first check that none got onto yourself or others. If so, deal with that first. Small quantities of sulfuric acid can be neutralised using sodium bicarbonate, which once neutralised, can be cleaned up and disposed of.

Personal protective equipment (PPE) is required. The recommendation for working with these chemicals includes:

- **wrap-around eyeglasses**
- **nitrile gloves**, which you change every time you touch acid or base containing vessels
- **overalls**, or clothing you don't mind getting a few holes in, and
- always wash your hands after moving from the work area

Pro safety tip: **always store acid in a 'bunded' area, so if there is a failure of your acid container, the spill is caught in the bunding. We do this by merely placing the acid container inside a slightly larger container.**

We trust that at this point, you have informed yourself of the materials with which we are working and established a safe work area. Let's get into the process.

Just what is happening?

Fear not; this is as much chemistry as I will go into. Because anodising aluminium is an electro-chemical process, we need to consider what happens at the anode (which is the workpiece) and the cathode in the reaction. Fig.1 shows the general arrangement.

At the anode: $2Al + 3H_2O \Rightarrow Al_2O_3 + 6H^+ + 6e^-$
At the cathode: $6H^+ + 6e^- \Rightarrow 3H_2$

The resulting anodising reaction is:

$2Al + 3H_2O \Rightarrow Al_2O_3 + 3H_2$

The Al_2O_3 is a conversion of the aluminium on the surface of the workpiece. Hydrogen gas (H_2) is generated at the cathode, and can be seen as bubbles – so definitely no smoking anywhere in the area and care must be taken to eliminate electrical sparks.

The electrolyte, generally sulfuric acid, is not consumed in the anodising reaction. So the acid bath can be reused many times.

Anodisation actually converts a very thin part of the surface of your workpiece into aluminium oxide. The process described in this article produces a 25-50 micron layer, which usually leads to an insignificant change in thickness.

The way that aluminium oxide grows on the surface of the part creates a hexagonal, honeycomb-like structure. The structure is tiny, but large enough for dyes to be captured within.

So once we have anodised a part, we can take advantage of this structure and use it to hold coloured dyes.

Anodising time

We have just seen that anodising is a chemical conversion of the part, driven by an external power source. So how much current is required and for how long?

The current at which you anodise has several impacts on the type of finish you get. This is a variable that you will need to experiment with. I'll provide some rules of thumb, and the results of my experience as a starting point:

- lower temperatures and higher voltages (to achieve the required current) can lead to very thick finishes
- the type of aluminium alloy present, and any impurities, has an impact on the result
- the thickness of anodisation layer is largely a function of how long you anodise
- if you use a voltage source rather than current source, the current will vary throughout the process

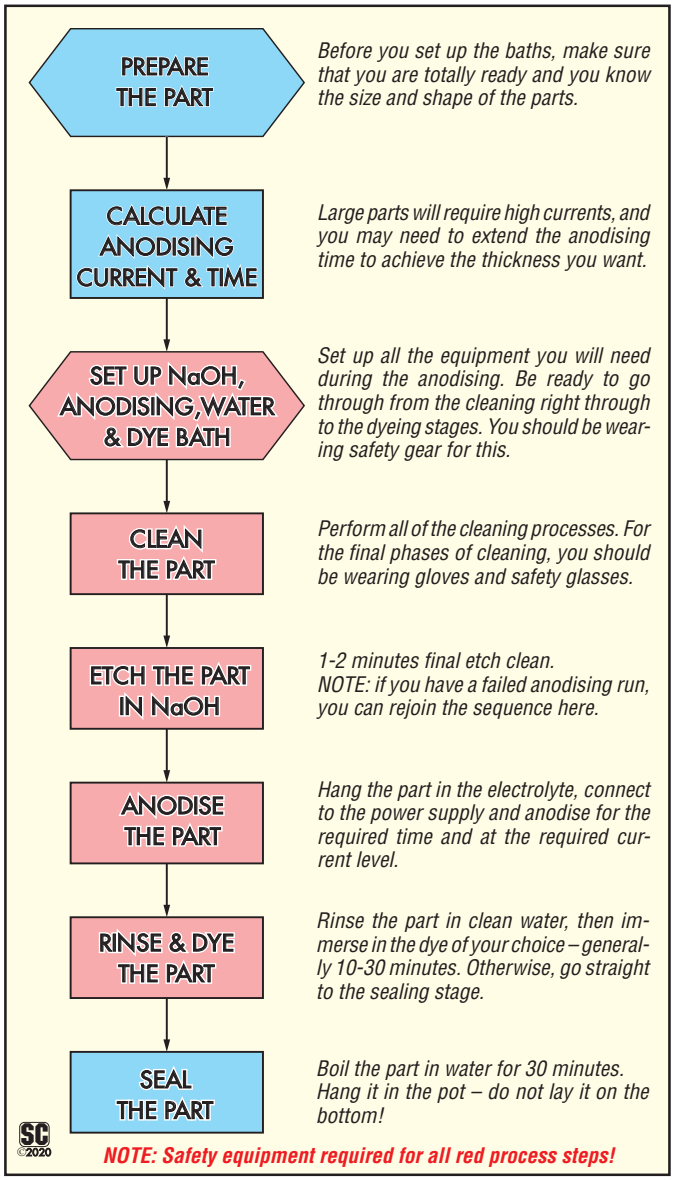

PREPARE THE PART
Before you set up the baths, make sure that you are totally ready and you know the size and shape of the parts.
CALCULATE ANODISING CURRENT & TIME
Large parts will require high currents, and you may need to extend the anodising time to achieve the thickness you want.
SET UP NaOH, ANODISING, WATER & DYE BATH
Set up all the equipment you will need during the anodising. Be ready to go through from the cleaning right through to the dyeing stages. You should be wearing safety gear for this.
CLEAN THE PART
Perform all of the cleaning processes. For the final phases of cleaning, you should be wearing gloves and safety glasses.
ETCH THE PART IN NaOH
1-2 minutes final etch clean.
NOTE: if you have a failed anodising run, you can rejoin the sequence here.
ANODISE THE PART
Hang the part in the electrolyte, connect to the power supply and anodise for the required time and at the required current level.
RINSE & DYE THE PART
Rinse the part in clean water, then immerse in the dye of your choice – generally 10-30 minutes. Otherwise, go straight to the sealing stage.
SEAL THE PART
Boil the part in water for 30 minutes. Hang it in the pot – do not lay it on the bottom!
SC ©2020
NOTE: Safety equipment required for all red process steps!

Fig.3: a flow chart which explains all the steps required in anodising. It is not absolutely essential to dye the part, nor even to seal it – but it will be much tougher if you do! Note the comment regarding safety equipment: it's for YOUR protection!

Remember that anodising is all about a chemical reaction, and the current the process draws is a result of the chemical reaction moving ions around. So controlling the current is much preferable to the voltage, as this gives you some control of the chemical process.

One common rule often used to determine the current required is "the rule of 720", where:

$$\text{minutes to anodise} = \frac{\text{thickness of the desired layer in mils} \times 720}{\text{amps/ft}^2}$$

Converting this to metric units gives us the rule of 3.12 (almost pi, but not quite!):

$$\text{minutes to anodise} = \frac{\text{thickness of the desired layer in microns} \times 3.12}{\text{amps/dm}^2}$$

Yes, we are using the decimetre (dm) as a unit. One square decimetre is 100cm^2, eg, 10x10cm.

One of my tests used three pieces of aluminium of 30cm^2 each (see Fig.2).

So we had a total of 90cm^2 or 0.9dm.

I wanted a 50 micron thick coating, so the calculation was:

$$\text{minutes to anodise} = \frac{50 \times 3.12}{(\text{amps} \div 0.9)}$$

This works out to 140 minutes (50 x 3.12 ÷ 0.9) ÷ amps.

Try to keep the anodising current in the region of 1-3A per 100cm^2, if for no other reason than this will give you a reasonable time to anodise the part to a 20-50 micron thickness.

You will note that for large parts, this might require a very high current source.

I have not tried anodising whole rack cases, but if your power supply cannot deliver the required current, you just need to anodise at the highest available current setting and let it run for as long as required.

Acetone is used to clean the parts to be anodised of any oily residue. It is readily available at hardware stores.

Sodium Bisulfate, an alternative to Sulfuric Acid, is also readily available – a good source is your local pool shop, where it is sold as pH Decreaser.

The process – a workflow

Fig.3 shows a basic workflow for anodising, with the steps you will need. They are described in more detail below. There are many variables, especially in the parts you wish to anodise and the equipment you have available.

The steps include preparation, setting up the anodising, staining and sealing. I suggest that you start at a small scale and run some test pieces before ramping up to large parts.

Remember that large parts will require large baths and power supplies.

Anodising bath electrolyte

While it is not commonly used, it is possible to anodise using sodium bisulphate as the electrolyte instead of sulfuric acid. I ran several tests using sodium bisulphate and got identical results.

There is not a lot of discussion on the internet about this alternative. Some commenters suggested that the chemical bath may need to be replaced regularly, as opposed to sulfuric acid, where the same bath can be kept and used many times.

I suspect that they may have a point, but for the few tests I ran, it gave perfect results.

If you are having trouble finding sulfuric acid and only wish to run a few experiments, then this is a real option as the materials are available at your local pool or hardware store.

You won't need a whole roll of lead – it's quite expensive so if you can beg or borrow a smaller quantity (maybe a local builder or plumber?) you will be better off!

Aluminium wire is commonly available at better hardware stores – it is sold as "Tig" welding wire.

Sodium bisulphate is inexpensive, and if you are not planning to set up a factory, the possible short lifespan of the electrolyte bath is not a big deal.

Electrolyte preparation steps – sulfuric acid

1) Purchase standard battery acid. I bought some with an SG of 1.28, or about 36% concentration, and diluted it to between 10-15% concentration. Add acid to water!

2) Select your anodising bath container. Make sure it is much deeper than your part, can be carried easily and emptied easily.

3) Fill to 2/3 of the final bath depth with deionised/distilled water.

4) Then (and this is the last time I will mention this) wearing your personal protective equipment, add acid to the water, filling the bath to the final depth. NEVER add water to acid, as this can lead to the water boiling and splashing!

Electrolyte preparation – sodium bisulphate

The steps are the same as above, but you need to add 20% by weight of sodium bisulphate crystals to the water for the final solution. So if you want 5L of electrolyte, add 1kg of sodium bisulphate crystals to 4L of water. Note though that this will give you a little less than 5L – to be honest, I cut a corner and just used a little extra water to make it up.

We found the crystals took ages to dissolve. They eventually did, though.

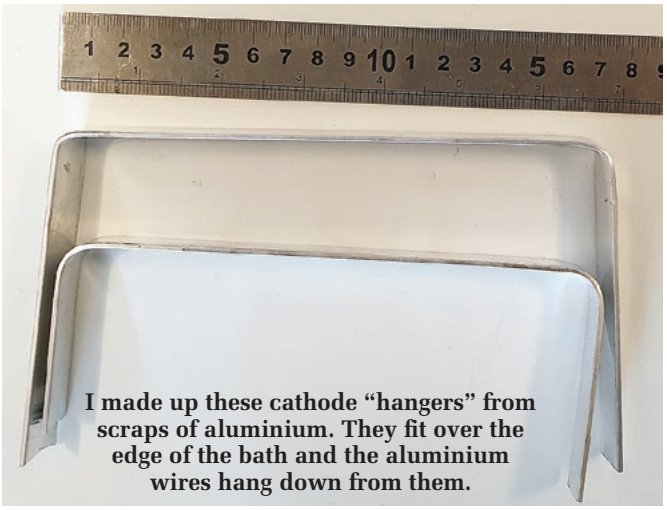
We noticed that the sodium bisulphate bath was less clear than the sulfuric acid bath. I suspect that this is because the purity of pool chemicals is not great, while battery acid usually is very well controlled.

The bath was somewhat cloudy, though over several batches of anodising, it did clear up a bit. Your experience may be different.

Note that when using sodium bisulphate, you're likely to get sodium sulphate generated and deposited at the cathode. So you may need to clean the cathode after a few runs or else you might find that you have to apply a higher and higher voltage to get sufficient current flow.

Cathode preparation

The cathodes can be either aluminium or lead. Aluminium will not last, but lead can be tricky to find in small pieces. Digging around in the back of an old shed usually unearths a few sheets of lead, which is commonly used for flashing on roofs. You may also be able to get your hands on lead curtain weights without spending much.



I made up these cathode "hangers" from scraps of aluminium. They fit over the edge of the bath and the aluminium wires hang down from them.

You will know when you find it, as it is heavy, very ductile and often crusty looking if it is old. That is OK, a good scrub with a scourer will make it ready to use. The cathode surface area should be approximately the same as the area of your workpiece, although that is not critical.

If you want to buy some lead, it is available from hardware stores, but you may be forced to buy more than you want, and it is not cheap.

A friendly chat with your local plumber might be a cost-effective alternative, especially if facilitated with a six-pack of your plumber's favourite beverage.

I simply cut and bent the lead sheet to fit my container. Make sure your connection to the cathode is outside the electrolyte, or your leads will very quickly become corroded, and may contaminate your acid bath.

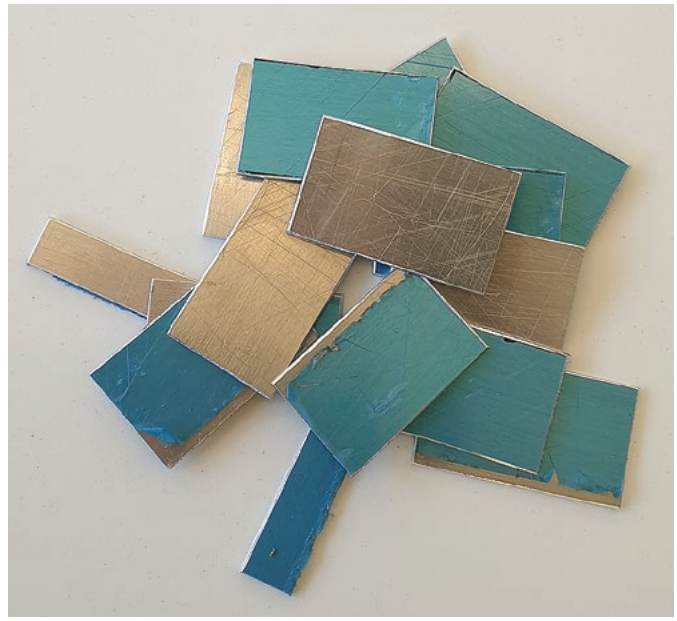
Even though it gets "dirty", the cathode is not used up in this reaction, so it can be reused many times.

As noted above, if lead is too much of a hassle, heavy aluminium foil such as you find on takeaway containers also works.

I used this in my first tests without a problem. Should you happen to have a stash of titanium sheet, this would be ideal.

Unfortunately, my personal jet fighter needs all of its titanium bits!

The surface finish on your parts before anodising will determine how they come out. Once anodised the surface finish is protected by the hard anodised layer. Spend that extra five minutes before anodising to get them perfect.



Lead makes a great cathode. Lead sheet is not pretty, especially after use, but that is fine – you can use it over and over again.
(Right): these are some scrap pieces I used for trialling my anodising processes and chemistry. It's always wise to do many trials on offcuts and scraps to get timing and chemicals correct before the "real thing".

As you may have guessed, the cathode will eventually connect to the negative end of your DC power supply.

Part preparation

Preparation is absolutely everything in terms of the finish you achieve on your parts. Anodising produces a micron-scale later of aluminium oxide, which will do nothing to hide a scratch or dent. Dyeing the part simply changes the colour, and does nothing to fill defects or blemishes. If you spend five minutes preparing the part, you will be able to tell at the end!

That said, if you are restoring an old vehicle and want to anodise old aluminium parts that you have cleaned up, plain anodising will certainly protect that part from the elements and ensure that all your hard work lasts.

There are a few steps to prepare your parts for anodising:

1) make the parts (if not already made)
2) prepare the surface
3) scrub clean
4) clean of oil and finger grease
5) etch the surface to remove any residual anodising

We'll go through these briefly.

Manufacturing the parts

If you are making the parts yourself, it is a good idea to make sure there is a conveniently located hole that can be used to hang the part during the anodising process.

For the demonstration parts, I simply drilled a small hole in the corner. But you might not have that luxury with your part!

It is imperative that there is good electrical contact between the hanging wire and your part.

One option that we've taken in the past is to drill a hanger hole in a spot that will be hidden from sight in the final application, and make "paper clip" type hooks from aluminium wire to feed through that hole and hang the part in the bath.

Surface preparation

The first level of preparation is to ensure the surface is free of scratches and dents. This starts when manufacturing your part. Just as if you were planning on painting the surface, use material that is free of scratches and dents, be careful how you mark it up and do not leave tool marks on the part.

Finishing your edges requires either clean cuts (for example, using a guillotine), or you need to file and sand the edges smooth.

When filing, remember that you need to work from a coarse to a fine file, and probably will want to end with sandpaper to get a clean edge.

Scrub clean

Once your parts are made and finished to your satisfaction, they need to be cleaned of any surface contamination. Unless the surfaces are freshly machined (ie, you have just taken the part off a lathe or milling machine), you will need to clean the surface very thoroughly, including scrubbing off any existing anodisation layer on the surface.

This is generally done by taking a green scouring pad or fine sandpaper to the surface and scrubbing away any sign of anodisation, oil or other surface contamination. This needs to be a very vigorous process and should leave you with an immaculate and shiny part.

Work from say 400 grit wet and dry sandpaper through to 800 or even 1200 grit. The surfaces I finished with 1200 grit came out very smooth and clean looking. You need to be careful to sand in straight lines and not leave scuffs on the surface.

Using wet and dry paper under running water assists with keeping the paper clean.

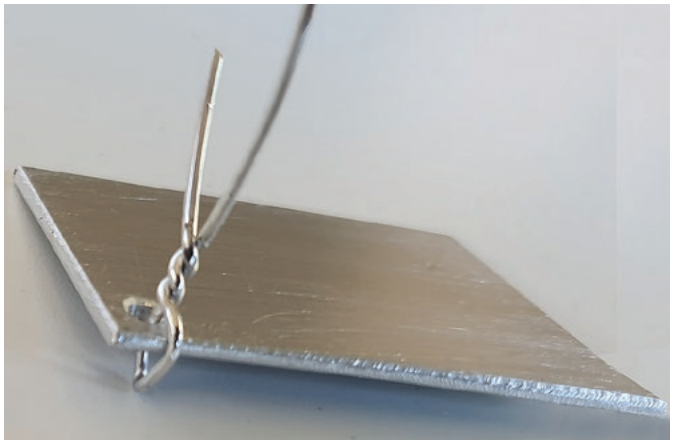
Clean away oil and finger grease

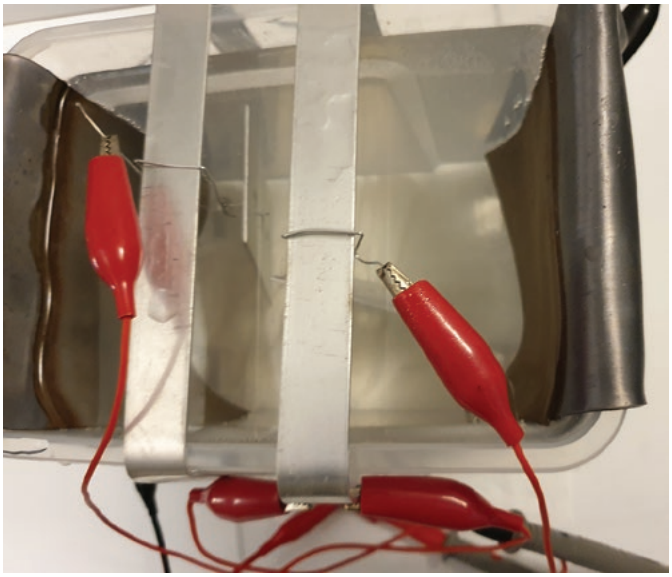
At this point, you need to glove up. This time, it is to keep you from contaminating the part with oil from your fingers.

Any oil deposited from here on will interfere with the anodising process. In one of my tests, I touched a part and once it was stained, it was obvious where it had been touched.

Clean the part(s) first with soapy water, then with acetone, by wetting a tissue with acetone and wiping the part down.

Use acetone in a reasonably ventilated area, and dispose of the tissues with care, as it is flammable. Once cleaned,





Achieving good electrical connection to your parts is essential. It is also not as easy as it might seem. Our main cause of problems was poor connection at the anode.

At right: we made up these "hangers" to support small pieces of work – the idea is to keep these out of the solution so they don't get anodised!

attach your connection wire.

As discussed above, having a cleverly placed hole that you can squish the wire into helps. Do this with your gloves on, and make sure the connection is solid.

Making the anode connection

To make your part an anode, you need to attach a piece of aluminium wire. Why use aluminium wire? If you put steel or copper into the bath, the electrolytic process will eat these away very quickly, and in the process likely cause the anodisation to fail.

By using aluminium wire, this is avoided, and the only effect is that **the hanger wire is anodised in the process.**

Aluminium wire is available as TIG welding wire from a hardware store (I patronised my local Bunnings). It will probably be hidden away in the tools section. Alternatively, if you have some heavy-duty power line cables laying around, they might use aluminium wire internally, so this could be a cheap source.

Ideally, the hole in your part should be just the right size to poke the TIG wire into, with a tight fit. I used a 0.8mm PCB drill for this, and squished the TIG wire so that it was tight in this hole. Alternatively, you could fold the wire over and push it into a screw hole.

Professional anodising systems use aluminium or titanium hangers which incorporate clips that firmly grip the part.

Etching the part surface

Place the part in the sodium hydroxide bath for 1-2 minutes to remove any remaining oxide layer. To prepare this bath, make a solution of 2% sodium hydroxide with clean water. That is about two spoons of pure NaOH per 500mL of water.

Keep your gloves and glasses on during this process.

Hold your part by the attached anode wire; do not put your fingers in the solution even with gloves on. By one minute, your parts should be fizzing away happily, and by two minutes, you can pull them out and move them to a clean water bath.

This water bath removes any residual sodium hydroxide before the part goes into the anodising bath.

Anodising

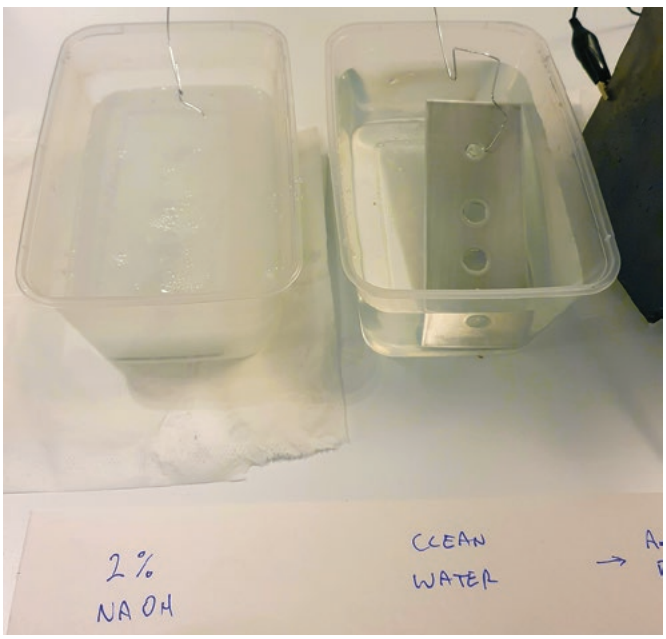
You are now ready to anodise your parts. You should have your anodising bath ready, with the cathode plate in and connected to your power supply, and a hanger of some sort that allows you to hang your parts in the bath. The bath should already contain the electrolyte.

Take your parts from the clean water bath and bend the hanger wire to allow them to hang in the anodising bath without touching the cathode or each other.

When hanging the parts, wear all your protective equipment. Do not put your hands in the electrolyte, even though you have gloves on.

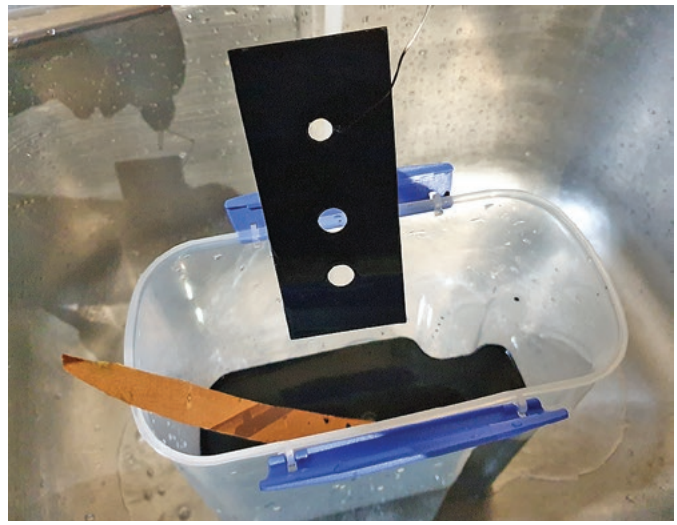
If you drop a part, use timber tweezers or similar to fish it out and then clean it off in water and start again.

Use clip leads to make sure that there is an electrical connection from the positive supply to the anode



Arranging your workspace is important. This shows how we lined out etch and rinse baths up to support a simple workflow.

This tub of green dye works particularly well. This is after a very brief dip – and shows that we had not properly mixed the powder in. Preparation is important.



This black dyed part used a specialist anodising dye, and worked extremely well – much better than some of the RIT fabric dyes (see the table below).

connection on your part. This might save you from using bad language later on!

Apply power and set the current to your desired level.

To check that there is a good connection to all your parts, take a clip lead off each one and ensure that the supply voltage changes (or current, if you are using a constant voltage power supply).

The anodising process will take quite a while. My test case took two hours. Most practical runs should be in the 1-2 hour range, possibly more if your parts are substantial.

Check from time to time that everything looks OK. Remember to put your glasses and gloves on every time you go near to the bath. Be prepared to dispose of a fair few pairs of gloves.

When the time is up, fish your parts out using tweezers and put them in a clean water bath. There will be a subtly grey finish to the parts. This is the raw anodised layer. They are then ready for staining and sealing.

Staining

To stain the parts, hang them in a stain bath. The time required depends on how dark you want the colour to come out and on the dye itself. In preparing this article, I tried out quite a few different dyes with mixed success. The most consistent outcomes were found with dyes sold especially for staining anodised surfaces.

I also had success with some (but not all) of the RIT dyes which are sold for colouring fabric.

Take a look at the photos to see a few of my test pieces.

Generally, 5-20 minutes is enough to stain parts. Note that the sealing process takes away a little of the colour depth.

If something went wrong in the anodising process (most likely due to a power supply connection problem), that part will not take any colour in the dyeing process. This is because the aluminium oxide microstructure is not there to hold the dye.

Sealing the parts

This simply involves immersing them in boiling water for 30 minutes. This seals off the top of the cells in the aluminium oxide and holds the dye in place. If you aren't dying the parts, you still need to seal off the top of the cells.

Use an old pot with a lid. I bought mine at a local op shop for a couple of dollars. Some dye is released during this process, and it's best not stain the expensive kitchenware.

Results and conclusions

I ran several test runs on some small pieces of aluminium to test out the process and a range of dyes. I found that the process worked well with both sulfuric acid and sodium bisulfate as the electrolyte.

Of the dyes I tested, many of them gave excellent colours. It is clear that anodising and staining can deliver both protective and decorative results.

With appropriate care and preparation, the process is safe and straightforward.

At left is my evaluation of the range of dyes tested, which are available from eBay and in your local store.

I have included some photos of the results of our tests, to show you the sort of colours you can achieve. You will see some scratches on these – that's because I was still learning some of the tricks that I have now passed on to you! SC

Dye	Result
Classic Plating Green (eBay)	*Very effective (specialised anodising dye)*
Classic Plating Black (eBay)	*Very effective (specialised anodising dye)*
RIT Tangerine powder	*Worked a treat*
RIT Denim Blue powder	*Very inconsistent and patchy result, though this was a powder dye; it might work better as a liquid.*
RIT Royal Blue liquid	*Worked OK*
RIT Scarlet Red liquid	*Worked well*
DYLON Velvet Black (Coles)	*Total failure*

Some dyes give a better result than others – and some are pretty hopeless! It really is a matter of trial and error (more errors than trials?).

COVID-19 – and getting your copy of SILICON CHIP

As Nicholas Vinen reports in his Editorial Viewpoint in this issue, despite the impact of COVID-19, SILICON CHIP is still in production, albeit with staff working from home. We aim to bring out each issue on time and with all the usual features and technical articles you've come to expect. But where does that leave you, our readers, in getting their hands on a copy each month when many readers can't, or don't wish to, leave home; many newsagents are closed or on reduced hours and so on?

You basically have three options:

(a) The best choice, by far, is to **subscribe to SILICON CHIP**. This will ensure your copy will reach your mailbox at the earliest possible date – and we have been assured that postal services will continue.

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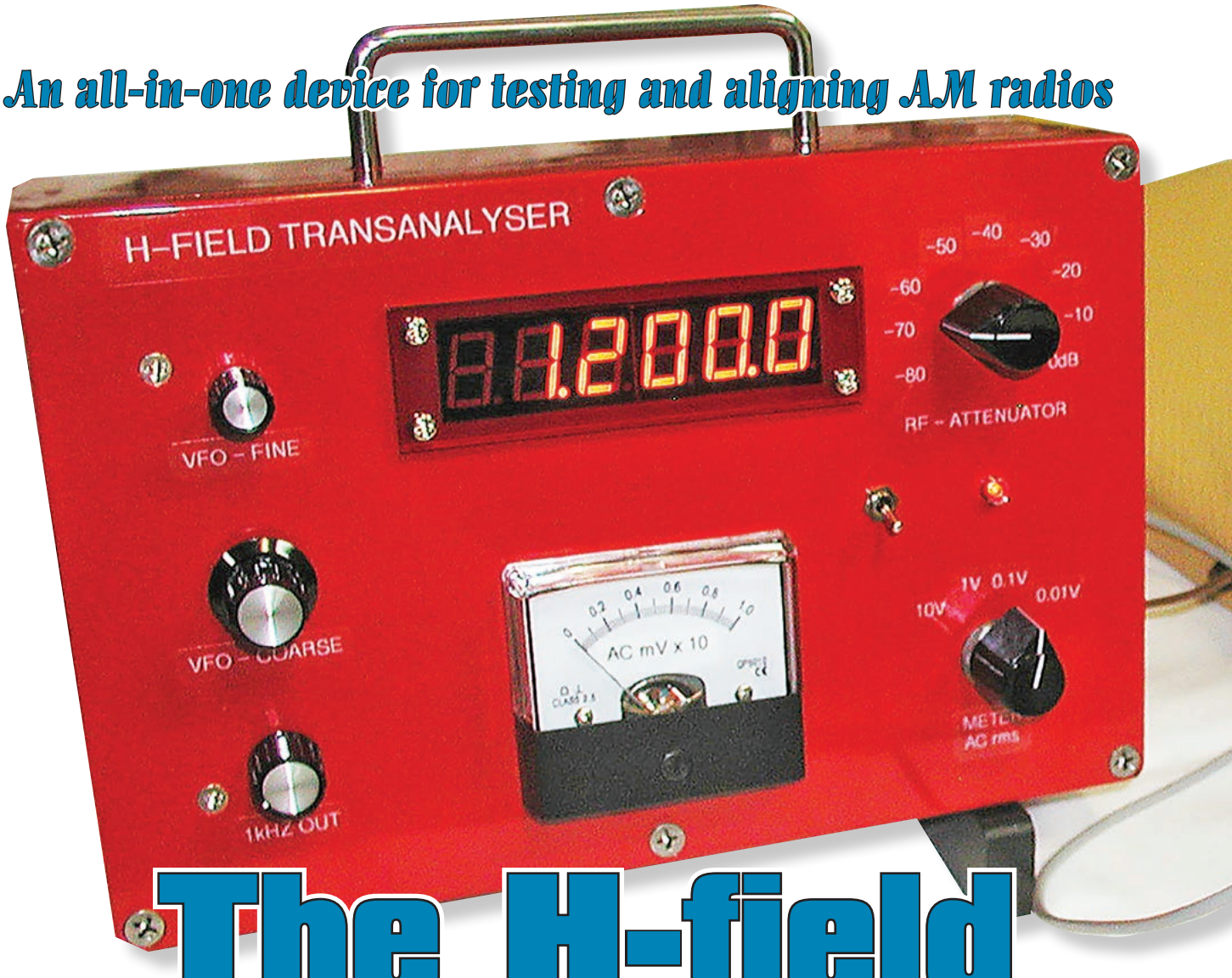
An all-in-one device for testing and aligning AM radios



The H-field Transanalyser

Many SILICON CHIP readers are into restoring, repairing or even building AM radio receivers. With this test set, you don't need to make any direct connections to the radio's front end. This ensures that the tests are realistic and the alignment is spot-on. While it's a fairly complex device, all the construction steps are quite straightforward and using it is a breeze.

I spent many years of adjusting and tuning up transistor radios using some very expensive laboratory RF generators and oscilloscopes.

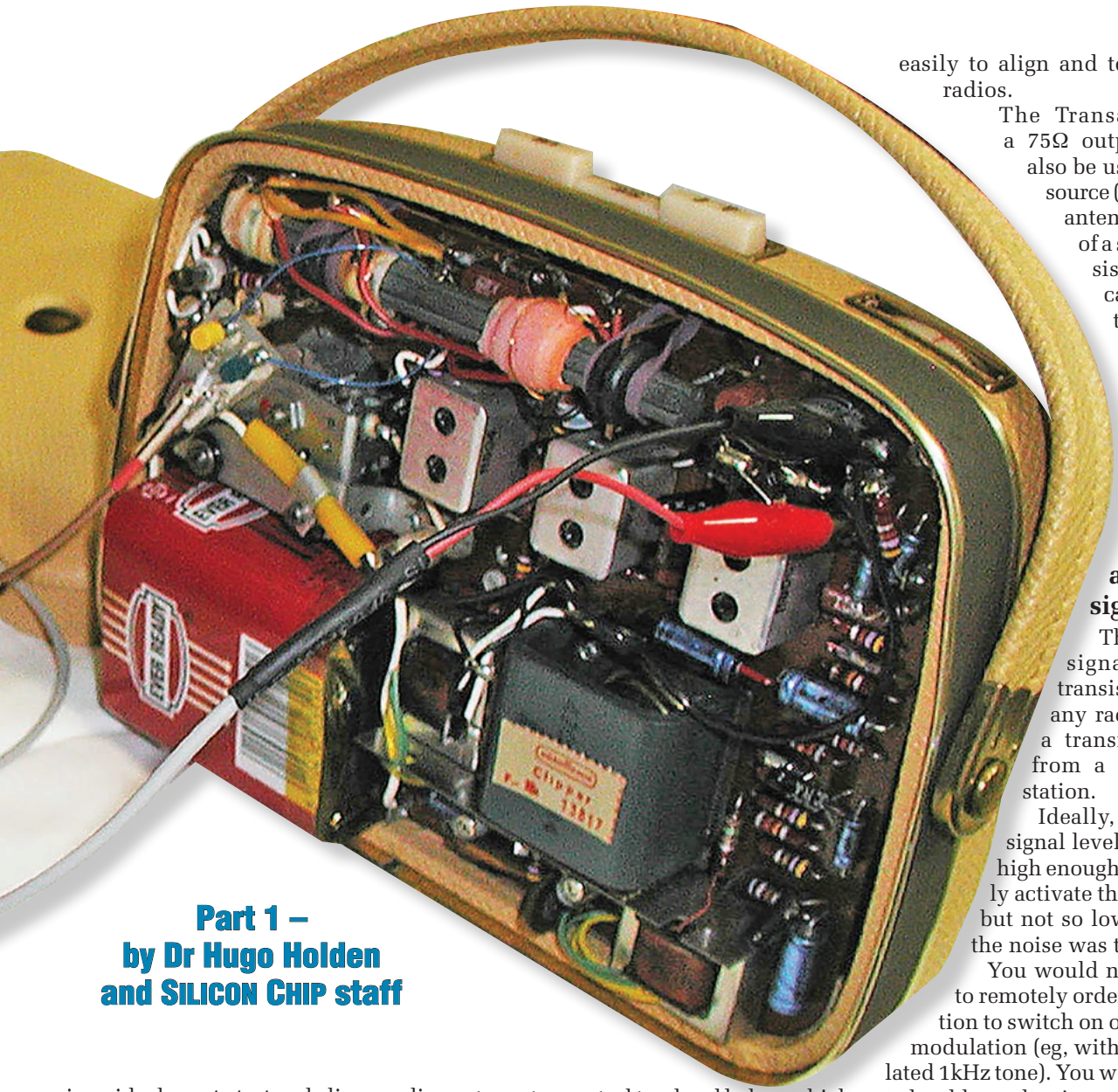
Eventually, I realised that it was best to avoid feeding signals directly into any part of a radio's circuitry.

While technicians often do this and it is recommended in service manuals, the coupling of any signals fed into a radio needs to be very loose, or else the stage that the generator's signal feeds into is always detuned to some degree.

Any adjustment made using this test signal will be partially (or sometimes wholly) incorrect after removing the generator's connection.

So I decided to create short-range loop transmitting antennas, driven by controlled energy, to generate near-field magnetic radiation.

By carefully controlling the level, modulation etc it is possible to provide a radio with signals of similar intensities to those that it would pick up from the magnetic component of the EM wave from a far-off radio station. This



Part 1 – by Dr Hugo Holden and SILICON CHIP staff

is an ideal way to test and align a radio.

This is called near-field radiation because the region close to the loop antenna, say within 10 meters, is much smaller than the wavelength of the transmission, eg, 300m for a 1MHz signal.

Also, as most small transistor radios do not have external antenna sockets, the ability to deliver a controlled and known RF voltage level into their input circuits is otherwise difficult.

The standard solution is to inject a signal into some part of the input circuit. But this gives different results than injecting a signal into a radio with external antenna inputs designed to handle a particular source impedance.

The H-Field Transanalyser described here is a system where an 'H field' is generated by a controlled RF source derived from a 1kHz-modulated variable frequency carrier wave. It has attenuator control to a level below which any transistor radio can detect. This magnetic radiation is coupled to the radio's ferrite rod with a single loop of wire around the ferrite rod, and the rod's tuned main winding area.

The H-Field Transanalyser gives the ability to both objectively and subjectively analyse the performance of an AM radio.

It also provides a 1kHz test signal for the radio's audio amplifier system. It is a complete tool to fully and accurately calibrate a broadcast band AM transistor radio, including the radio's intermediate frequency stages.

The VFO was made to go below 455kHz (to around 205kHz) so that most AM band transistor radio IF stages, including those which operate at 262kHz, can be aligned.

With another switch added, the frequency range can be down-shifted easily to align and test long-wave radios.

The Transanalyser has a 75Ω output so it can also be used as a signal source (with a dummy antenna consisting of a series 330Ω resistor and 250pF capacitor) over the range of 205-1800kHz. This is useful for aligning and testing valve-based AM radios.

The ideal alignment signal

The ideal RF test signal to align a transistor radio (or any radio) would be a transmitted signal from a distant radio station.

Ideally, the received signal level would be not high enough to significantly activate the radio's AGC, but not so low in level that the noise was too dominant.

You would need to be able to remotely order the radio station to switch on or off its carrier modulation (eg, with a 30% modulated 1kHz tone). You would also need to be able to alter its transmission frequency, to check the radio across the whole band for its sensitivity and frequency-dial calibration. Such a notion is impractical, of course.

However, if you consider that a transistor radio responds to the magnetic component of the far-field of a transmitted radio wave (ie, the H field), then a replica H field can be generated locally by a small loop placed around the ferrite rod antenna.

The loop is then driven by a modulated and controlled-level RF current source.

This is not a new idea. For example, a three-turn electrostatically shielded 10in diameter loop, placed 24in from the radio, is recommended for the alignment of English radios such as the Hacker Sovereign and others in the book *"Radio and Television Servicing"* by R. N. Wainwright, published

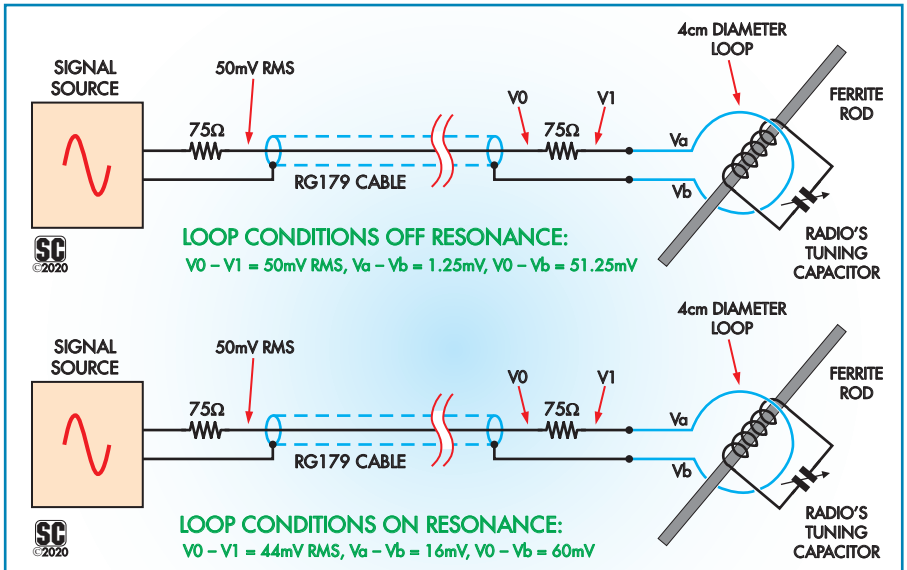


Fig.1: when the signal generator frequency is significantly different from the radio's tuned frequency, there is little voltage across the loop; most of the 50mV signal voltage is dropped across the 75Ω resistor in series with the loop. When the frequencies match, the voltage across the loop rises to around 16mV RMS.

by McDonald & Co in 1971.

But the exact signal level supplied by the generator was not specified, and the resultant H-field intensity is dependent on the exact spacing between the radio and the loop.

The H-field intensity is proportional to IR^2, where I is the loop current and R the radius of the loop. But it is also inversely proportional to $(Z^2 + R^2)^{1.5}$, where Z is the distance from the loop plane to the centre of the receiving antenna.

The H field (magnetic intensity in amps per meter) from the loop is converted to a B field (flux density in Teslas) by the ferrite rod.

The relationship is B = UoUrH, where Uo is $4\pi \times 10^{-7}$, and Ur is the relative permeability of the rod, which for a transistor radio is usually around 125.

Designing the H-field generator

My first experiment was to place a loop around a standard ferrite rod and tuning coil assembly on a typical AM broadcast band radio, over the main resonant winding area. I then loaded the loop with a series of resistors and observed the effect that this had on the performance of the tuned antenna circuit.

With the radio tuned to a weak distant station, I found that the loop needed to be loaded with less than 30-50Ω to noticeably reduce the sensitivity of the radio. The effect of loading it with 75-150Ω was only just detectable.

Therefore, I decided that a source impedance of 150Ω would be satisfactory to inject current into the loop, without altering the tuning conditions and Q of the radio's tuned antenna coil.

This impedance was organised by using a generator with a 75Ω output impedance and adding a 75Ω series resistor.

Fig.1(a) shows an RF source driving a small loop. The actual loop size is not too important, as it represents one magnetic turn around the ferrite rod. It is ideal if it passes over the central area of the main tuned winding on the rod. The wires leading to the loop can also be twisted together (or not) with little effect.

Experiments with a 1400kHz test signal showed that the reactance of a 4cm loop (with negligible DC resistance) is so low over the applied frequency range that it can be ignored. For example, with a 50mV RMS signal across the 75Ω resistor in series with the loop, the voltage across the loop was only about 0.8mV RMS.

Then, with typical radio ferrite rod (Ur = 125) through the loop's centre, still only about 1.25mV was developed across the loop. This is the case when the radio's input tuned frequency is significantly different from the generator frequency.

However, when the tuned circuit on the radio's ferrite rod is tuned (peaked) to the same value as the applied RF frequency, the impedance of the loop elevates, and the phase of the voltage across the loop becomes in-phase with the generator voltage. Fig.1(b) shows the voltages under this resonant condition.

The voltage across the loop rises to about 16mV and V0 elevates by about 10mV, to 60mV as the load current is reduced. Therefore, resonance effects coupled back by mutual coupling into the loop results in the applied loop current dropping, but only by a little. The previous 50mV developed across the 75Ω resistor immediately in series with the loop drops from 50mV to 44mV RMS.

Due to the relatively small change in the loop current (and therefore H-field intensity drop) from a non-resonant to a resonant condition, I considered it unnecessary to create a constant-current drive for the loop. Therefore, I decided to use my test arrangement of a 75Ω generator with a 75Ω series resistor, in the final design.

One major advantage of this is that the Transanalyser unit can act as a standard 75Ω output modulated laboratory generator where required (say, for aligning valve radios).

Transanalyser design

In my design, 0dB on the attenuator results in an unmodulated 50mV RMS signal applied to a 75Ω load from the 75Ω source. Philips used this standard arrangement in their wonderful PM5326 RF generator.

The Transanalyser, in effect, produces an identical RF output to the PM5326 generator, but has a stepped attenuator (rather than a variable one) and operates over the frequency range of 205-1800kHz. In contrast, the PM5326 goes to 125MHz. However, as noted above, this range can be easily altered by changing the timing capacitor on the MAX038.

The VFO in the Transanalyser has been built around a MAX038 frequency synthesiser IC, primarily because its output level is perfectly uniform across the whole frequency range.

I tried other discrete transistor VFOs based on the red oscillator coils from transistor radios, but they required many additional parts to level the output over the full tuning range.

Although the MAX038 is obsolete, they are still easy to get. But some of these chips coming of China are re-

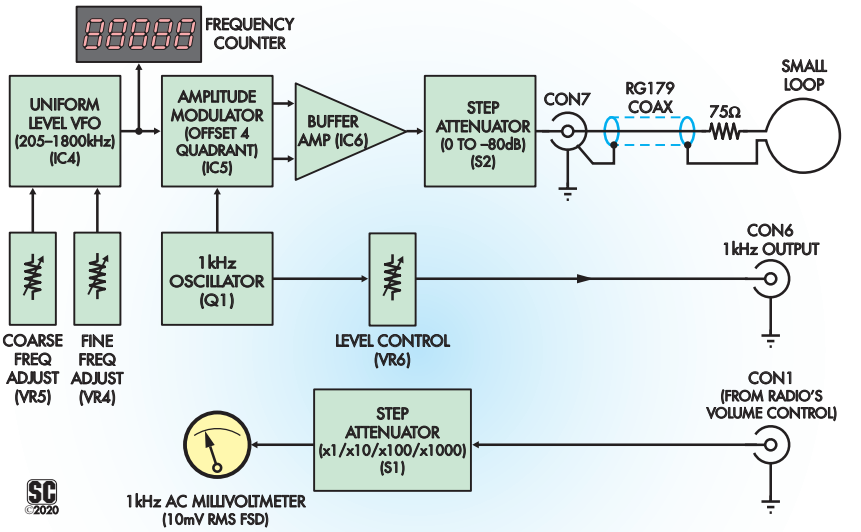


Fig.2: the Transanalyser block diagram. VR4 and VR5 set the VFO frequency, which is read out on an LED display. The VFO output and 1kHz test signal are fed into modulator IC5, and the 30% modulated signal is then buffered by IC6 and fed to the 0-80dB step modulator before going onto CON7 and the test loop. A separate 1kHz output is available, as well as a millivoltmeter which has a full-scale reading of between 1mV and 10V in decade steps.

labelled fakes. All the working chips are of Maxim origin, though; the fakes appear to be another type of 20-pin IC that has been re-labelled.

The block diagram of the Transanalyser is shown in Fig.2. Two potentiometers are used to adjust the VFO frequency, to allow for both quick changes and fine-tuning. Its output is fed to a frequency counter, so you can see the frequency you've set, and then on to the modulator, which is also fed from a 1kHz oscillator to provide the modulating signal.

The output of the modulator is buffered and then fed to a nine-step attenuator. The attenuator output goes to a BNC socket. A length of coax is used to connect the small loop with integral 75Ω resistor, to produce the H field.

The 1kHz oscillator output is separately fed to a level control and thence to a second BNC socket to provide a low-frequency test signal if required. A third BNC socket acts as a test input, and the signal from that is fed to a four-step decade attenuator and on to an analog meter.

Circuit description

The circuit of the Transanalyser is shown in Fig.3. You can see how the block diagram corresponds to this circuit by looking for the component designators mentioned in the block diagram; eg, IC4 is the VFO, IC6 is the mixer, IC3 is the mixer buffer etc.

The components which set the VFO output frequency are shown to the left of IC4. VC1 allows its range to be calibrated while trimpot VR2 is the carrier level calibration control. The signal from its wiper is AC-coupled to the pin 8 carrier input of mixer IC5, with a 1kΩ resistor from +5V supplying current to that input. The other carrier input at pin 10 is unused so is tied directly to +5V.

IC5 is an MC1496 transistor array, operating as a four-quadrant multiplier. This provides very linear amplitude modulation of an RF carrier. It needs to be biased correctly so that an offset is produced; otherwise, its output spectrum would be suppressed carrier double sideband modulation (DSB). The ±5V and 9V supplies are used to set up the required DC conditions for the MC1496.

NPN transistor Q1 operates as an RC phase-shift type sinewave oscillator, with component values chosen to get a low-distortion 1kHz sinewave. This signal is AC-coupled to the inputs of buffer op amps IC3a and IC3b, with a 100kΩ resistor to 0V to remove any DC bias.

I settled on this oscillator configuration after experimenting with op amp-based oscillators, including those stabilised with incandescent lamps. Q1 has significant DC degeneration to provide sufficient AC gain for the oscillator to start reliably, despite the expected hFE variations. The 1kHz waveform has some very mild distortion, but overall it is a good-looking sinewave.

The output of IC3b is fed to the 1kHz output at CON6 via level control potentiometer VR6, while the identical output from IC3a goes to modulation calibration trimpot VR3 and then into the pin 1 signal input of IC5.

The other signal input at pin 4 is unused and so is DC-biased to around 1V via a pair of resistors bypassed by two capacitors to ground, so that the mixer within IC5 is properly balanced.

The 2kΩ gain adjustment resistor between pins 2 and 3 of IC5, and the 3.9kΩ bias resistor from pin 5 to ground are required to set up the internal conditions for the mixer to operate properly.

In addition to loading the outputs at pins 6 and 12, the 300Ω resistors to +9V also supply current for the chip's output stage to operate.

The differential signals from these pins are AC-coupled to input pins 5 & 6 of 300MHz video op amp IC6b. This is configured as a low-gain differential amplifier. Its single-ended output is fed to non-inverting input pin 3 of IC6a, the other half of the dual op amp, which provides a further gain of two times. The output signal from IC6a then goes to the switched output attenuator via a 75Ω resistor.

This attenuator uses parallel pairs of resistors, with 150Ω//3.6kΩ (equivalent to 144Ω), 110Ω//3.9kΩ (equivalent to 107Ω) and 75Ω//1.8kΩ (equivalent to 72Ω).

These values set up the attenuation ratios for 10dB steps down to -80dB. The output impedance of this divider is 37.5Ω, so a pair of parallel 75Ω resistors in series with the switch output terminal sets the required 75Ω output impedance.

For properly testing radios, it must be possible to attenuate the RF signal below the level which any reasonable receiver can pick up.

My experience using the Philips PM5326 generator to test and align radios suggested that 10dB steps are adequate for the attenuator; there is no need for it to be continuously variable.

I decided to configure it as though it is a terminated 75Ω ladder attenuator with a 75Ω input impedance.

The source impedance is 75Ω ÷ 2 at each point along the ladder, provided the attenuator is fed with a 75Ω source impedance and also terminated by 75Ω.

The attenuator resistor values could have been doubled to give a 150Ω output impedance, and then the two parallel 75Ω resistors at the output would not be required. It would also require a lower input voltage for the same output signal.

But I decided against that as the lower impedance design helps to minimise capacitive cross-coupling effects within rotary switch S2.

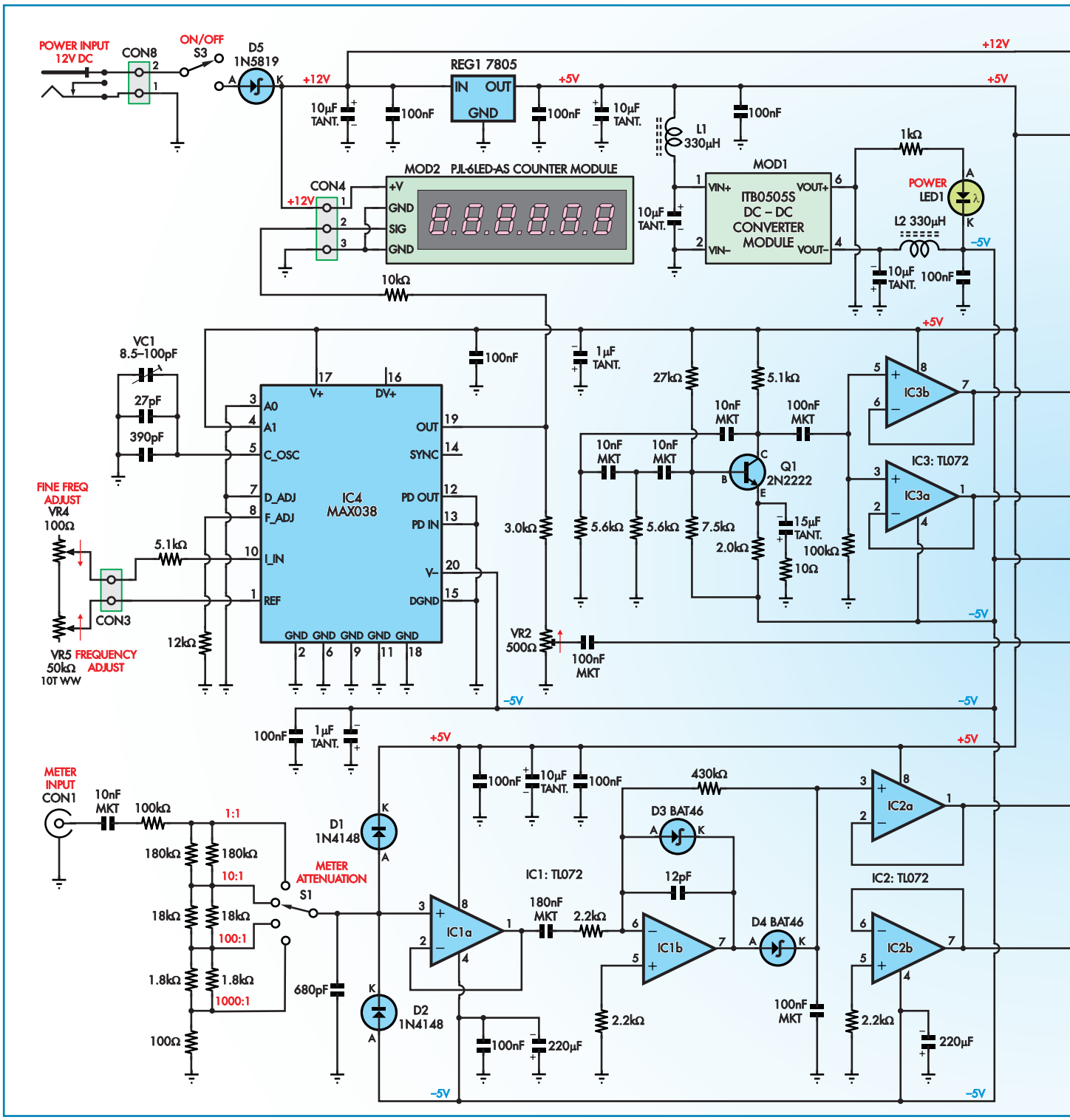
The result is an attenuator which is accurate down to -80dB with no leakage or cross-coupling effects detectable at AM radio frequencies.

IC6a has no trouble delivering the 200mV RMS required to get the required 50mV RMS output into a 75Ω load.

Metering section

CON1 is provided to feed an AC voltage back into the unit, to measure the output of a radio for a given input signal. This signal is AC-coupled to a high input impedance switched divider (200kΩ) to provide 10V (1:1), 1V (10:1), 0.1V (100:1) and 10mV (1000:1) ranges.

The 680pF suppresses any residual RF in the signal while diodes D1 and D2 protect the input of op amp IC1a from overload. IC1a buffers the signal,



which is then AC-coupled to IC1b, operating as a precision half-wave rectifier. This produces a DC voltage proportional to the peak negative voltage from the attenuator.

The meter is designed to receive signals from the test radio's volume control; the precision rectifier operates to very low levels for accurate readings.

The filtering was designed so that its calibration is accurate at 1kHz, the modulation frequency of the received carrier. The response for low and high-frequency audio signals is reduced to help noise immunity. It works as follows.

IC1b operates as an inverting amplifier; its non-inverting input (pin 5) is tied to ground, and both the incoming signal and feedback go to its inverting input (pin 6).

When the incoming signal swings negative, to maintain 0V at pin 6 (to match the voltage at pin 5), output pin 7 must swing positive.

Pin 7's voltage increases until diode D4 is forward-biased, charging up the 100nF capacitor at its cathode. Feedback via the 430kΩ resistor results in the pin 6 input reaching 0V. So the gain of this stage is 195 times (430kΩ÷2.2kΩ).

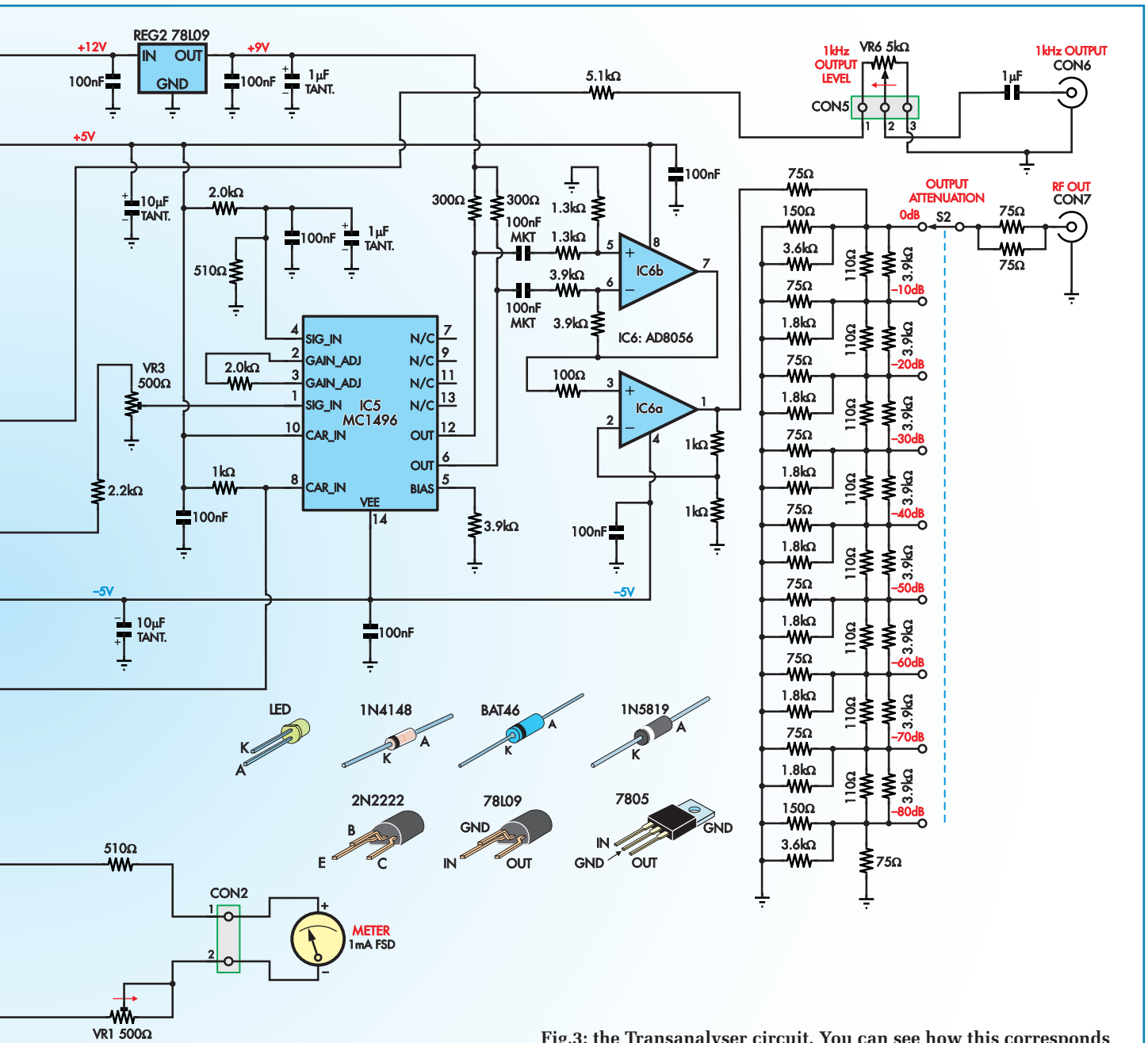


Fig.3: the Transanalyser circuit. You can see how this corresponds to the block diagram in Fig.2 by matching up the component designators. The VFO section around IC4 is at left, with the phase-shift oscillator based on Q1 to its right. IC5 and surrounding components form the modulator while IC6 is a differential amplifier feeding the stepped attenuator based on rotary switch S2. The metering section is at the bottom, with the power supply at the top.

SC ©2020 **H-FIELD TRANSANALYSER**

The rear panel is quite spartan, housing only the power input (right) and from the left the meter in, 1kHz signal out and, of course, the RF out socket. All user controls are on the front panel.

With D4 forward-biased, diode D3 is reverse-biased, so it has little effect. The 12pF capacitor improves this stage's stability by rolling off its gain at high frequencies.

When the signal from the attenuator is positive, IC1b's output pin 7 goes negative, forward-biasing diode D3 and so pulling its pin 6 input down to 0V. In this case, D4 is reverse-biased so the 100nF can only slowly discharge through the 430kΩ resistor.

The voltage across the 100nF capacitor representing the incoming signal level is then buffered by op amp IC2a and fed to the positive end of the 1mA meter via a 510Ω fixed resistor. The negative end of the meter is connected to the output of op amp IC2b, which is held at 0V, via 500Ω calibration trimpot VR1.

The meter scale is set up in millivolts, so VR1 is adjusted to give a maximum reading with say 1V applied to CON1 and S1 set to the 10:1 (1V) range.

Frequency counter

The frequency counter is a PJL-6LED model from SANJIAN Studio, which is good value at around $15, including delivery. This type is readily available on eBay and AliExpress. It has an adjustable display brightness, eight modes and resolution setting (and remembers its settings).

For this project, it is set to 100Hz resolution mode. On brightness level 3, the display is still bright, and the current consumption only around 30mA. I also tested an LCD-based counter, and it actually consumed more current! The timebase has a very nice crystal oscillator assembly and the ones I bought had spot-on calibration.

Power supply

The circuit runs from 12V DC. There are three regulated rails: +5V, -5V and +9V. The ±5V rails provide a split supply to run all the ICs in the circuit, plus the oscillator built around transistor Q1.

The 9V rail is used only to power the output stage of mixer IC5. It is derived from the incoming 12V supply by linear regulator REG2.

The only component that runs directly from the incoming 12V supply is the frequency counter module.

Like the 9V rail, the +5V rail is derived from +12V by linear regulator REG1. However, generating the -5V rail is a little more involved. This is done by an isolated DC/DC converter, MOD1. This module produces a 5V regulated output from a 5V input, but its outputs are floating. This means that we can connect its VOUT+ terminal to ground, and get -5V from its VOUT- terminal.

Inductor L1 forms an LC filter for the input of MOD1, so that any switching noise caused by pulses of current drawn at its input does not make its way back into the circuit.

Similarly, switching noise and ripple at the -5V output is filtered by a pi filter made from a 10uF capacitor, inductor L2, and the following 100nF and 10uF capacitors.

LED1 lights up when the -5V rail is present to indicate that the circuit is operating. Switch S3 provides power on/off control while diode D5 protects the circuit against accidentally reversed supply polarity.

PCB assembly

The first Transanalyser prototype was made using protoboard connected to bare copper laminate with point-to-point wiring and many 'air-wired' components.

However, building it this way is difficult and laborious, and the chance of making mistakes is high.

So we have designed a proper double-sided PCB for this project and had it commercially manufactured. It is coded 06102201 and measures 125 x 112mm. This is shown in the overlay diagram, Fig.4.

All the components are through-hole types, except for the attenuator resistors. This has the advantage that those resistors are over an essentially unbroken ground plane. Start by fitting those attenuator resistors. Each will be printed with a code indicating its value, such as 362 (36 x 10^2) or 3601 (360 x 10^1) for 3.6kΩ.

Once you have located the correct resistor for a position, tack solder one end in place and check that part's alignment. If it's off, re-heat that end and gently nudge the body. Once it's in position, solder the other end, wait a little while for the joint to solidify, then add a little fresh solder (or some flux paste and heat) to the first joint.

Make sure your iron tip touches the edge of each resistor and the PCB pad, so that solder flows onto both.

Once those are all in place, install the fixed-value through-hole resistors in the usual manner. It's best to check their values with a DMM set to measure ohms before installation, as the colour-code bands are easy to misread.

Follow with the five diodes. There are three different types, so don't get them mixed up, and make sure they are orientated as shown in Fig.4.

If you are using IC sockets, fit them now. Make sure their pin 1 end notches are orientated as shown. Sockets

make it easier to replace a damaged IC, but they are not great for long-term reliability. So if possible, we suggest you instead solder the ICs directly to the board. If doing that, make sure you don't get the similar TL072 and AD8056 ICs mixed up, and be extra careful to get their orientations right!

Next, bend the leads of the 7805 regulator down and attach its tab to the PCB using a 10mm machine screw and nut. Make sure the screw and nut are done up tight before soldering and trimming the leads.

This is a good time to fit the PC pins which will support the shields later. A total of 49 pads are provided, but we suggest that you only need to use about half of these (21). The suggested pads used to support the shield are circled in Fig.4 and on the PCB. Push the PCB pins down firmly and solder them. You will need a hot iron due to the thermal mass of the copper they are soldered to.

If your PCB pins are a tight fit, take care when inserting those near components. While it's a little tricky, you can hold them in the jaws of a pair of snub-nose pliers, sticking out the front, then carefully force them into the holes. Those which are further away from components could be hammered in.

Alternatively, use slightly smaller PCB pins (0.9mm diameter), which are not such a tight fit, or component lead off-cuts.

Now you can fit the three identical 500Ω trimpots, followed by the single trimmer capacitor (VC1). Then install regulator REG2, which is in a small plastic TO-92 package. Bend its leads out to fit the PCB pads before soldering it in place.

Transistor Q1 may come in the same TO-92 plastic package, in which case you mount it in the same manner as REG2. If it's in a TO-18 metal can package, unfortunately, the pinout is reversed compared to the TO-92 package; in other words, with the leads pointing down and the base at the rear, the left-hand lead is the collector while the emitter is on the right.

We've added an extra base pad for Q1, near the front, to make it easier to fit the TO-18 package version but it's still going to be a bit of a squeeze, and you will need to bend the base lead a bit so that it's nearly between the other two to match the PCB pads.

It's a good idea to wait until the surrounding capacitors have been fitted before installing Q1 in the TO-18 package.

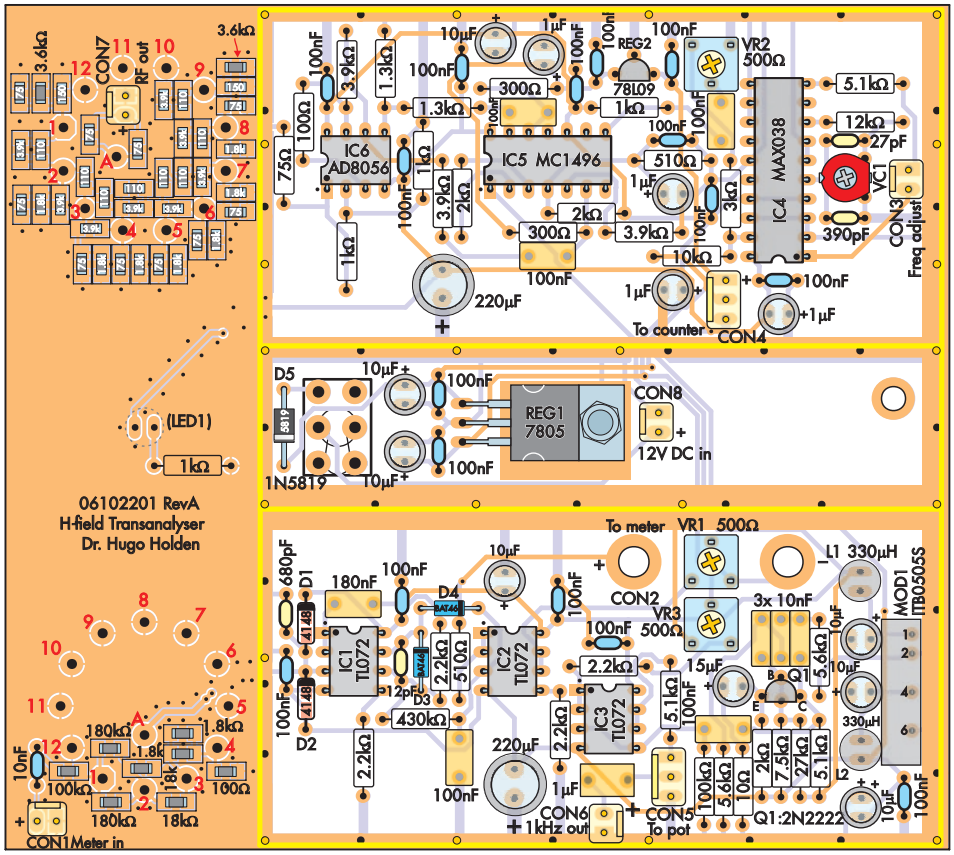
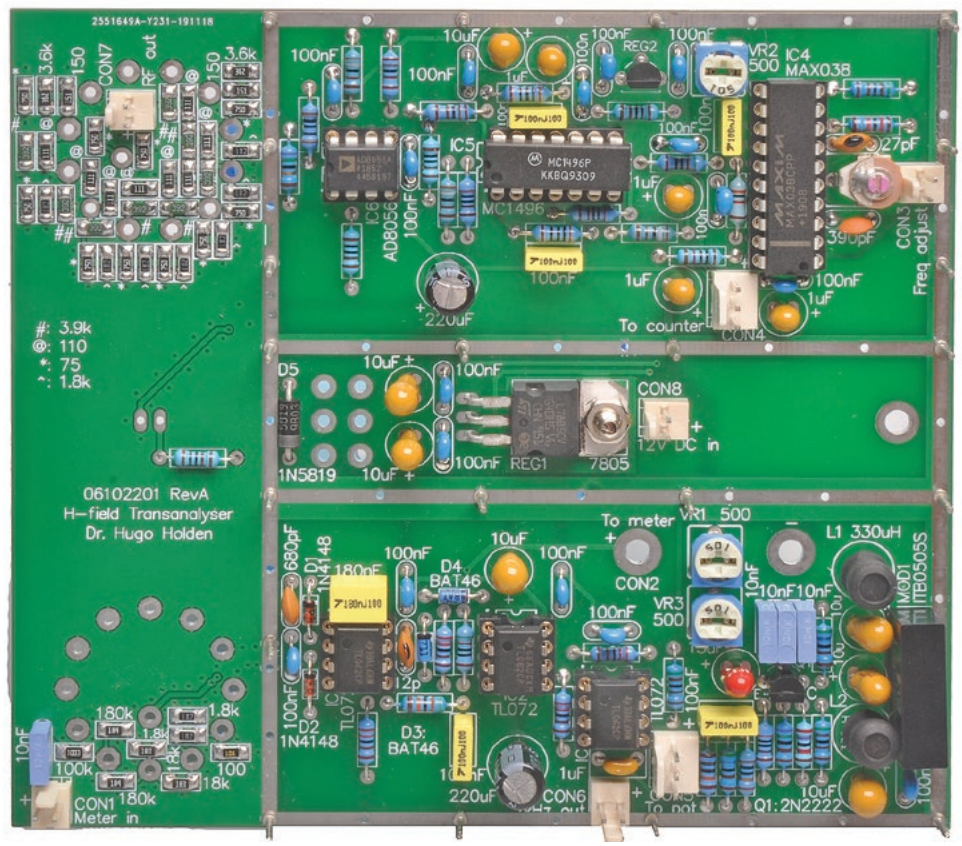


Fig.4: most, but not all components are mounted on this double-sided PCB. It has extensive ground planes, but shielding plates are still required between the three major sections where shown. They are supported by, and soldered to, numerous PC stakes. The major off-board components are potentiometers VR4-VR6 and the power and signal input/output connectors, all of which connect via locking headers.



Parts list – H-field Transanalyser (AM Radio Alignment Aid)

1 double-sided PCB, code 06102201, 125 x 112mm
1 222 x 146 x 55mm sealed diecast aluminium enclosure [Jaycar HB5050]
1 12V DC, 400mA+ regulated plugpack
1 set of front and rear panel labels for enclosure
1 ITB0505S isolated 5V to 5V DC/DC converter (MOD1)
1 PJL-6LED-AS 6-digit red frequency counter module (MOD2)
1 laser-cut acrylic bezel for the frequency meter
1 0-1mA MU45 moving-coil panel meter [Altronics Q0500A, Jaycar QP5010]
1 0-1mV paper label for the analog panel meter
5 2-pin polarised headers (CON1,CON3,CON6-CON8)
7 2-pin polarised plugs with pins (for CON1,CON3,CON6-CON8 & frequency meter)
2 3-pin polarised headers with matching plugs and pins (CON4,CON5)
2 330µH high-frequency ferrite bobbin chokes (L1,L2)
2 single-pole, 2-12 position rotary switches (S1,S2)
1 chassis-mount DPDT toggle switch (S3) [eg Altronics Cat S1345; Jaycar ST0355]
1 chassis-mount DC barrel socket (to CON8; pin diameter to suit plugpack)
1 chassis-mount BNC socket (to CON7, RF out)
2 chassis-mount RCA or BNC sockets (to CON1 [meter in] & CON6 [1kHz out])
5 knobs to suit S1, S2 & VR4-VR6
1 3mm LED bezel
1 12mm-long M3 tapped spacer
6 M3 x 10mm panhead machine screws
1 M3 x 10mm countersunk machine screw
3 M3 hex nuts
21 0.9-1mm PC pins (or use component lead off-cuts)
2 brass strips [eg K&S 12.7mm x 0.41mm x 304.8mm; ebay]
4 small rubber feet with mounting hardware
1 1m length of shielded cable
1 1m length of RG179 coax with a BNC plug at one end
1 RCA or BNC (to suit CON1) to 2 x alligator clip cable
1 200mm length of light-duty figure-8 cable
1 250mm length of wire-wrap wire (aka Kynar)
4 8-pin DIL sockets (optional; for IC1-IC3 & IC6)
1 14-pin DIL socket (optional; for IC5)
1 20-pin narrow DIL socket (optional; for IC4)

Semiconductors

3 TL072 dual JFET-input op amps, DIP-8 (IC1-IC3)
1 MAX038 function generator IC, DIP-20 narrow (IC4)
1 MC1496 balanced modulator/demodulator IC, DIP-14 (IC5)
1 AD8056 dual 300MHz video op amp, DIP-8 (IC6)
1 7805 5V 1A linear regulator, TO-220 (REG1)
1 78L09 9V 100mA linear regulator, TO-92 (REG2)
1 2N2222A or MPS2222A NPN transistor, TO-92 or TO-18 (Q1)
1 3mm green LED (LED1)
2 1N4148 small signal diodes (D1,D2)
2 BAT46 schottky signal diodes (D3,D4)
1 1N5819 1A schottky diode (D5)

Capacitors

2 220µF 10V electrolytic
1 15µF 6.3V tantalum electrolytic
7 10µF 16V tantalum electrolytic
4 1µF 16V tantalum electrolytic
1 1µF 100V MKT
1 180nF MKT
16 100nF MKT or multi-layer ceramic
5 100nF MKT
4 10nF MKT
1 680pF ceramic
1 390pF ceramic
1 27pF ceramic
1 12pF ceramic
1 8.5-100pF trimcap (VC1) [Jaycar RV5722]

Through-hole resistors (all 1/4W 1% metal film)

1 430kΩ	1 100kΩ	1 27kΩ	1 12kΩ	1 10kΩ
1 7.5kΩ	2 5.6kΩ	3 5.1kΩ	3 3.9kΩ	1 3kΩ
4 2.2kΩ	3 2kΩ	2 1.3kΩ	4 1kΩ	2 510Ω
2 300Ω	1 100Ω	1 75Ω	1 10Ω	

3 500Ω mini horizontal trimpots (VR1-VR3)
1 100Ω 16mm linear potentiometer (VR4)
1 50kΩ 10-turn linear potentiometer (VR5) [eg, RS Cat 536-11-503]
1 5kΩ 16mm linear potentiometer (VR6)

SMD resistors (all 3216/1206 size, 1%)

2 180kΩ	1 100kΩ	2 18kΩ	8 3.9kΩ	2 3.6kΩ
9 1.8kΩ	2 150Ω	8 110Ω	1 100Ω	10 75Ω

Now mount the ceramic capacitors and then the MKT capacitors, none of which are polarised. See the capacitor codes table if you're having trouble reading their values.

Note that 16 of the 100nF capacitors can be ceramic (including multilayer) or MKT types, while five others must be MKT. These five have square outlines on the PCB, and are shown as MKT types in Fig.4.

The electrolytic capacitors, including the tantalum types, are polarised. In both cases, the longer lead is positive and must go into the pad marked with a + symbol in Fig.4 and on the PCB. Aluminium electrolytics also have a stripe on the negative side of the can, while tantalums normally have a + symbol printed on the plastic encapsulation nearest to the positive lead.

With all the capacitors in place, if you fitted IC sockets earlier, plug all the ICs into their sockets, taking care not to fold up any of the leads under the bodies.

Don't get IC6 mixed up with the other 8-pin chips.

Next, fit the two inductors; they are identical and not polarised. Follow with the two-pin locking headers (CON1, CON3 and CON6-CON8) and three-pin locking headers (CON4 and CON5). We've shown suggested orientations, but these are not critical as you can make up the plugs to suit later.

The next step is to cut your tinplate/brass sheet into 5-10mm wide strips and bend those strips around the PC pins you installed earlier.

There are various ways to achieve the desired result, which is to surround all three main sections on the right side of the board with shield plates.

We suggest that you use two strips, one to surround the top section, extending down at the left side to touch the bottom section; and one to surround the bottom section, extending up at the right side to touch the top section. This is shown as lines on the PCB.

Cut and bend the strips to shape, then solder them to the PC pins in the corners and at the ends of the strip, and finish off by soldering them to all the other PC pins.

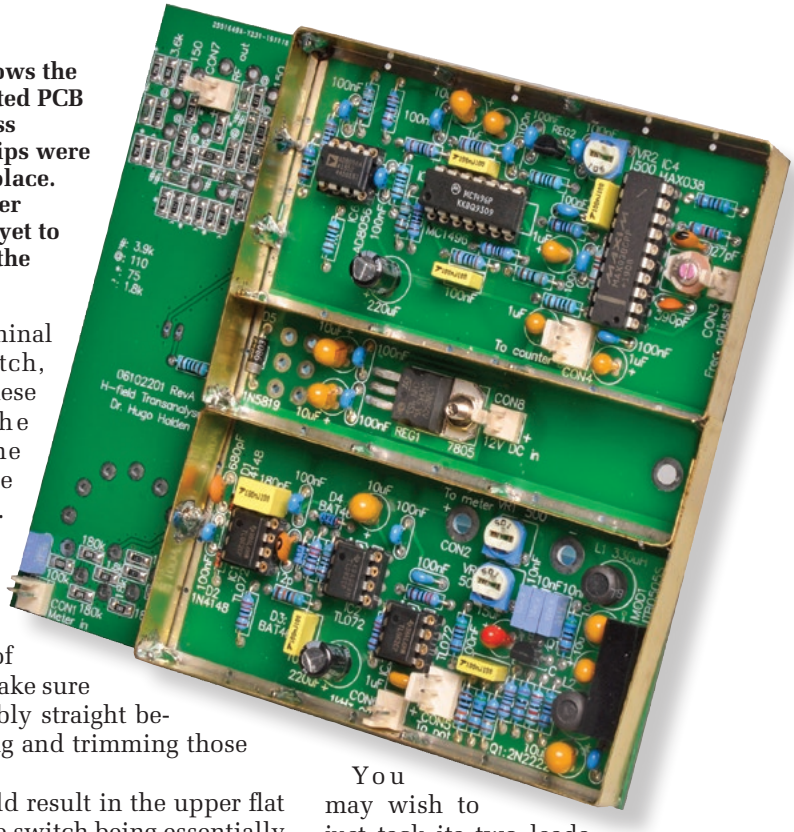
Now mount the switchmode module (MOD1) as shown. Push it right down onto the PCB. It can only fit with the correct orientation. That just leaves the three switches, which are all fitted to the underside of the PCB.

Before fitting S1 and S2, cut down their shafts to around 15mm above the threaded boss, so that when the knobs are pushed on, the bottom of the knob sits about 8mm above the top of the threaded boss. Also cut off the small locating posts in the bases, as we won't be using them.

You also need to adjust the two rotary switches to set them to the correct number of positions; four for S1 and nine for S2. To do this, rotate each switch full-anti clockwise, then remove the nut and lock washer and gently prise off the indexing plate beneath. Re-insert this with its pin going into the hole between the digits "4" and "5" for S1, and between "9" and "10" for S2, then re-attach the washers and nuts.

Now you can push these switches down into the underside of the PCB, ensuring that they are in the right positions and sitting flat before soldering all the pins.

That just leaves on/off switch S3. Solder 20mm lengths of tinned copper wire (or component lead off-cuts) to each terminal of this switch, then feed these through the pads via the underside of the PCB. The switch body should sit about 14mm off the surface of the board. Make sure it is reasonably straight before soldering and trimming those wires.



This shot shows the near-completed PCB after the brass shielding strips were soldered in place. The only other components yet to be fitted are the switches.

This should result in the upper flat surface of the switch being essentially level with the base of the panel meter, when it is fitted later (we're leaving it off for now, as it can only be permanently fitted when mounting the PCB to the case).

Finally, fit LED1 on the same side as switches S1-S3, with the base of its lens sitting just below the tops of those switches.

Make sure its longer lead goes to the pad marked "A".

You may wish to just tack its two leads to the PCB and not trim them just yet, as it may require a slight height adjustment when you fit the board into the case later.

Next month

We'll describe how to complete the wiring, test and calibrate the unit, put it all together in the case and give some advice on how to use it to test and align radios. SC

Through-hole Resistor Colour Codes

Qty.	Value	4-Band Code (1%)	5-Band Code (1%)
❑ 1	430kΩ	yellow orange yellow brown	yellow orange black orange brown
❑ 1	100kΩ	brown black yellow brown	brown black black orange brown
❑ 2	27kΩ	red violet orange brown	red violet black red brown
❑ 1	12kΩ	brown red orange brown	brown red black red brown
❑ 1	10kΩ	brown black orange brown	brown black black red brown
❑ 1	7.5kΩ	violet green red brown	violet green black brown brown
❑ 2	5.6kΩ	green blue red brown	green blue black brown brown
❑ 3	5.1kΩ	green brown red brown	green brown black brown brown
❑ 3	3.9kΩ	orange white red brown	orange white black brown brown
❑ 1	3.0kΩ	orange black red brown	red violet black brown brown
❑ 4	2.2kΩ	red red red brown	red red black brown brown
❑ 3	2.0kΩ	red black red brown	red black black brown brown
❑ 2	1.3kΩ	brown orange red brown	brown orange black brown brown
❑ 4	1kΩ	brown black red brown	brown black black brown brown
❑ 2	510Ω	green brown brown brown	green brown black black brown
❑ 2	300Ω	orange black brown brown	orange black black black brown
❑ 1	100Ω	brown black brown brown	brown black black black brown
❑ 1	75Ω	violet green black brown	violet green black gold brown
❑ 1	10Ω	brown black black brown	brown black black gold brown

SMD Resistor Codes

Qty.	Value	Code
❑ 2	180kΩ	184
❑ 1	100kΩ	104
❑ 2	18kΩ	183
❑ 8	3.9kΩ	392
❑ 2	3.6kΩ	362
❑ 9	1.8kΩ	182
❑ 2	150Ω	151
❑ 8	110Ω	111
❑ 1	100Ω	101
❑ 10	75Ω	750

Small Capacitor Codes

Value	µF Value	IEC Code	EIA Code
180nF	0.18µF	180n	184
100nF	0.1µf	100n	104
10nF	0.01µF	10n	103
680pF	N/A	680p	681
390pF	N/A	390p	391
27pF	N/A	27p	270
12pF	N/A	12p	120

SERVICEMAN'S LOG

A shed full of tools

By Dave Thompson

I love tools, and I'm not ashamed to admit it. Ever since I was old enough to understand what was going on, I enjoyed going through dad's array of tools and admiring their form and build quality. I learned early on that having the right tool for the job (and the skills to use it) meant you could accomplish pretty much anything.

Dad also instilled in me the benefits of tool quality. By the time I joined the airline as a wet-behind-the-ears apprentice, I already had what I thought was a decent tool kit, but it was nothing compared to the tools they issued to us.

I got most of my tools during the first six months, but others came my way over the following years, usually when posted to a new section that required more specialised tools. For example, the instrument workshops used a vastly different toolset than the radio/radar shop or when working on 'the line' on the airport apron, turning aircraft around.

All were the best money could buy at the time, and probably still are. So even though we were paying for our tools by way of a small amount taken from paycheques over the following years, they seemed like a gift from God at the time.

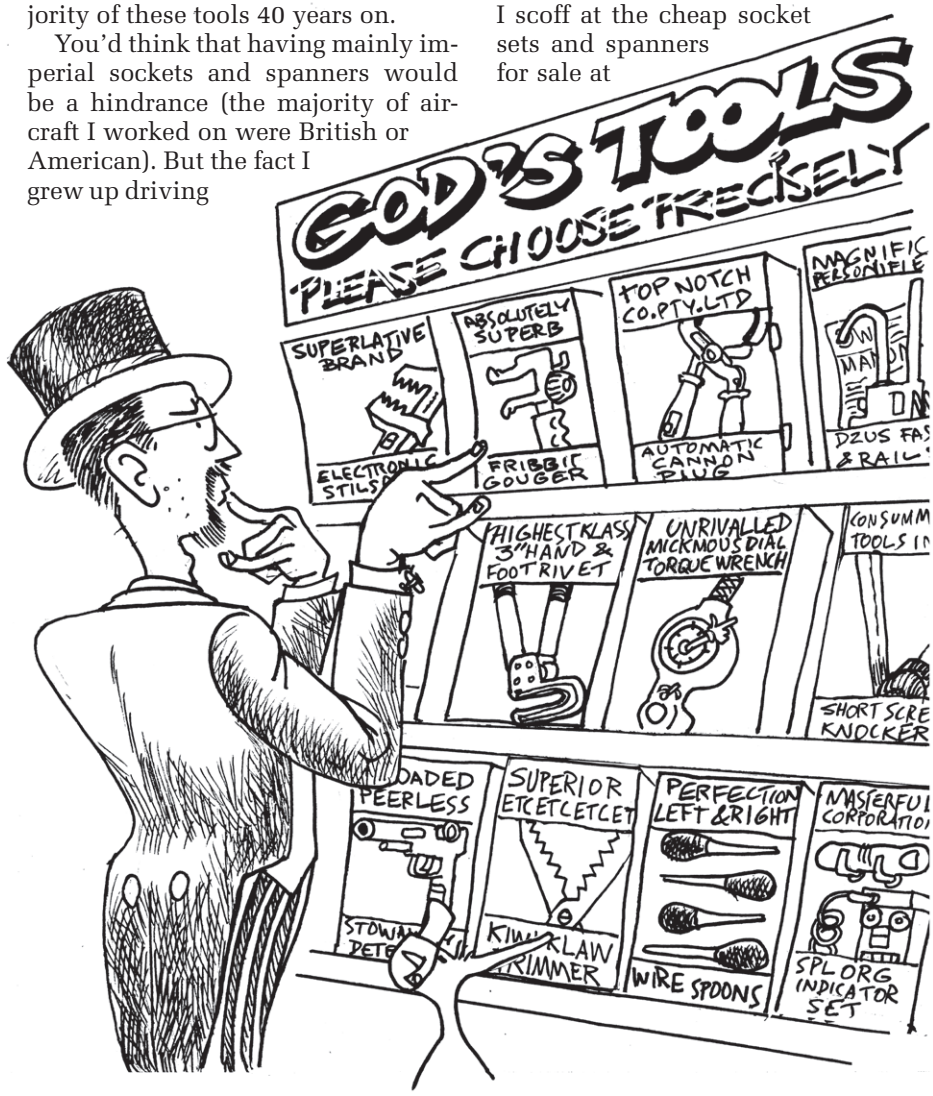
Thirty-six of us started at the airport on the same day, all 'engineering apprentices', so we were issued the same set of basic tools. After three or so months of common training, both practical and academic, six of us split off from the pack and began our own curriculum, learning more avionics-specific stuff.

So I had a lot of tools I never ended up using on an actual aircraft, but rest assured they've all been put to good use anyway! I still have the vast majority of these tools 40 years on.

You'd think that having mainly imperial sockets and spanners would be a hindrance (the majority of aircraft I worked on were British or American). But the fact I grew up driving mostly British cars meant that I still used them regularly.

Only the finest for me, please

One of the downsides is that this made me somewhat of a tool snob; I scoff at the cheap socket sets and spanners for sale at



ALL WERE THE BEST MONEY COULD BUY AT THE TIME, AND PROBABLY STILL ARE

Items Covered This Month

- The toolshed
- The intermittent audio analyser
- RF interference, part deux
- LED lamp repair
- LED motion lamp modification
- Induction cooktop repair

*Dave Thompson runs PC Anytime in Christchurch, NZ.

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Email: dave@pcanytime.co.nz

the local motoring shops. After all, buying cheap tools can actually cost more in the long run, not only from having to replace those tools when they wear out (soon!), but in lost productivity as well.

How many of us have purchased a set of screwdrivers only to twist the handle off the first time we used them? Or stripped the Phillips heads round trying to undo a stubborn screw? They can be just a complete waste of money.

Almost all the screwdrivers, spanners, hammers and sockets I own were issued by the airline or purchased years ago, and because I avoid using them for purposes they weren't designed for, they are still as good as new.

I once purchased an expensive, high-quality set of screwdrivers as a gift for a family member, thinking they would appreciate it. When visiting a few months later, I was horrified to see all the drivers bent out of shape; he'd been levering his car engine out with them – or at least, trying to! I guess there's no helping some people.

Dad also gave me some of his tools when he no longer needed them. I don't do a lot of machining, but if I ever take it up, I will never have to buy any reamers, cutters, clamps, vices or dial gauges. And I have enough drill bits of various sizes to use each one once and then throw it away!

I also inherited an excellent engineer's benchtop drill press, to which dad had made some modifications. Most drill presses of this type suffer from at least some float in the quill assembly (the part of the machine with the spinning chuck which goes up and down). As a general rule, the cheaper the drill press, the more play it has and therefore, the less accurate it is.

My own expensive pedestal-mounted drill press, which I used to make everything from project chassis to furniture and guitars has minimal play in the quill, but it's still a lot compared to dad's.

Dad's special tool requirements

As I've previously written, dad made small-scale gas turbine engines for model aircraft. This was long before you could just go out and buy one. He had to build most of the components from scratch, but he used a modified car turbocharger housing and its bearings and impellors as the basis of the engine.

Everything else, such as the nozzles, combustion chambers and fuel tubes had to be fabricated. I recall him experimenting with various materials and custom-made tools, with varying degrees of success.

Due to the size of some of the parts, he faced many challenges, and soon discovered that some of his tools were not up to the job.

He fashioned the fuel tubes for his engines from specially-made 1mm brass tubing. He had to drill a series of tiny holes at exact increments around these tubes; using a large drill press to do this job was far from ideal. He even had to make a chuck to hold the tiny drill bits.

He soon found out that even the minimal play in the quill on this machine prevented him from accurately forming the holes. So he machined a whole new quill assembly and mounted it in high-spec bearings. With a dial indicator stuck to the bed, even if I lean on the chuck in any direction with the quill at its lowest extended reach, I can barely get the indicator pointer to budge.

It was therefore a 'no-brainer' to make this my primary drill press. Even though I don't do anything that requires such high precision, it is good to know I have it.

I also inherited all the tiny drills dad used, and though I'll likely never use them, I have them just in case (the tool-owner's mantra!).

This sums up my tool philosophy: buy (or otherwise obtain) the best quality tools you can afford, and they will likely never let you down.

Disaster strikes

However, after moving dad's drill-press from our old place to my current workshop, it just wouldn't go. There is nothing worse than needing a tool, and it doesn't work (or isn't sharp).

I knew it had power because the built-in lamp turned on when the light switch was toggled. So there was either a fault in the motor circuit, or the motor had failed.

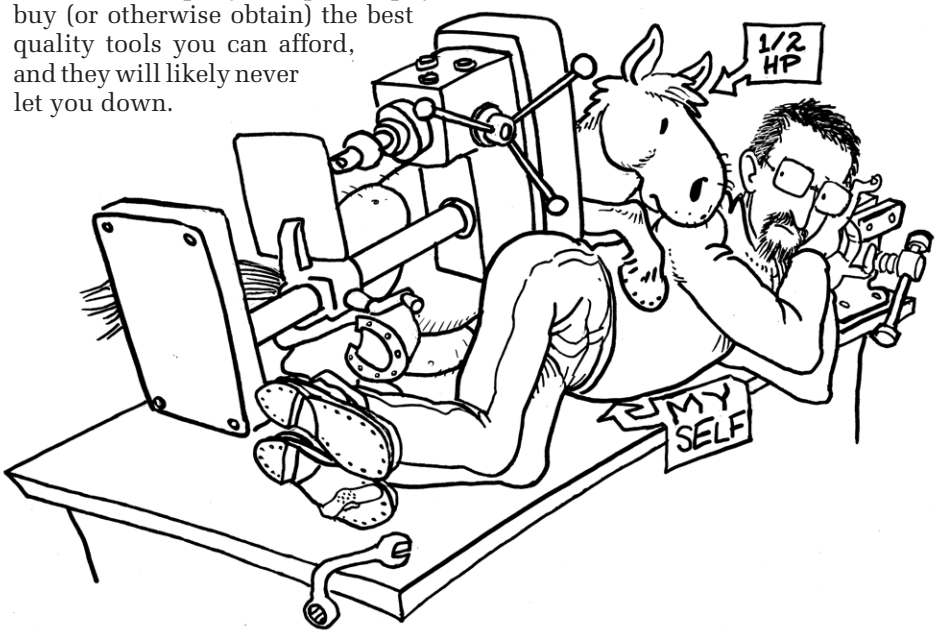
While used ¼ and ⅓ horsepower motors are a dime a dozen on local auction sites and can be (relatively) inexpensive, anything new or rated above that starts incurring a hefty premium. I don't think the ½ horsepower motor mounted at the top rear of the drill press is the original; I have vague memories of dad telling me he'd upgraded it.

Even though the mounting system allowed for various sizes of motors to be fitted, I'd like to stick with the larger motor if possible.

But before ordering a replacement, I had to determine what was going on with this one. I had to work on the drill press in-situ; it took two of us to heft it into its current position on the workbench. However, I could lie it down by myself if necessary.

Desperately seeking solutions

The first thing I did was to ensure that the chuck, the three pulleys and two belts in the drivetrain were moving freely. This was simply a matter of turning everything by hand and



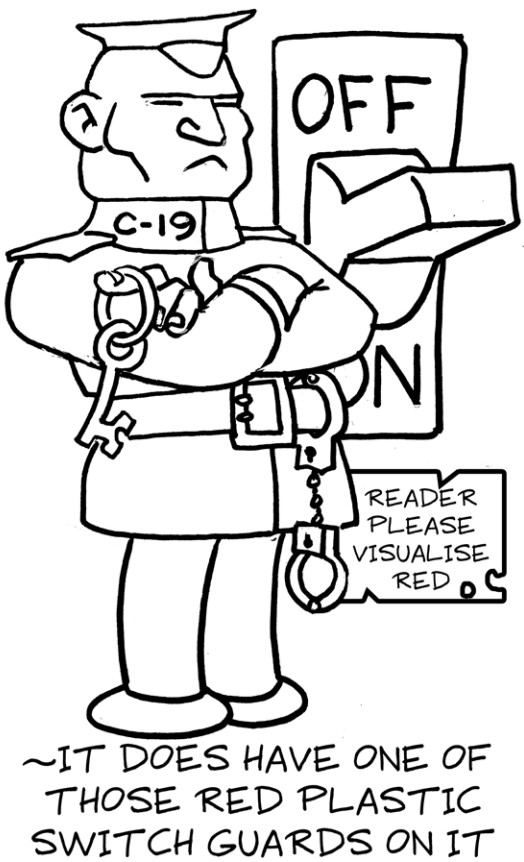
judging the amount of pressure required to move it.

If something had jammed the mechanism, I imagine that the motor would sit there and try to turn, or complain loudly, but I would be remiss if I started tearing into the guts of the machine without at least checking for freedom of movement first. It all turned easily and smoothly, so that wasn't it.

The next thing I looked for was a popped thermal switch or circuit breaker. Many motors, especially of this rating or higher, have one of these safety cut-out devices built-in. This push-to-reset type switch is usually found on the end of the motor housing, near the terminal block, or in some cases near where the power cables enter the motor.

These are either a simple circuit breaker, which will open if too much current is drawn, or a thermal-magnetic type device. They essentially do the same thing; cut power to the motor should a fault arise or if the motor is stalled or overloaded.

I pushed the breaker button on my motor. Even though it didn't feel as though it had popped, I tried switching on the motor again anyway in the vain hope of that being the problem.



No such luck; it was not a simple breaker activation.

I then removed the motor's flat metal terminal block cover, exposing the power connections underneath. Everything looked fine, with no loose wires or wayward terminals. I plugged it in and measured the voltage with my multimeter anyway, just to rule out something in the power plug and lead.

Many a device has been stripped down to spare parts, only to discover the problem was a broken or loose mains plug wire. I would never do something as silly as that, though! No, I wouldn't waste hours and hours disassembling and reassembling a device with a simple fault that I should have looked for before starting, all the time cursing my own stupidity… Ahem, now, where was I?

All measured as expected at the motor terminals, so I unplugged it again while I probed further.

The next step was to check the motor start capacitor. I've had several of these fail over the years, but as they are generally reliable devices, I didn't give it much chance that this would be the problem either.

I disconnected the terminals coming from it, made sure it was discharged (using a discharging wand – not a screwdriver!) and used my multimeter to make sure it wasn't obviously shorted or open circuit.

For the sake of thoroughness, I also used my capacitance meter to check the value, and it was within about 13% of the stated value on the case (25µF). So it wasn't going to be the cause of the problem either.

The fault could also be in the centrifugal switch inside the motor, but I left that option for last resorts, as fixing that would involve removing the motor and stripping it down.

Safety first!

Instead, my next step was to check the switch assembly at the front-right side of the machine. My old drill press has a simple on/off toggle switch on the front of the tower, though it does have one of those red plastic switch guards on it, like you get on military equipment or aircraft. The idea is that in a panic, it can be simply hit with a flick of the hand and switched off.

Dad's machine has a much better NVR (No Volt Release) style switch with separate on and off buttons, along with a paddle-off arrangement. I don't think this is original equipment, as the switch housing appeared to have been enlarged to accommodate the bigger NVR switch's footprint, so I'm guessing dad retrofitted that version at some stage.

NVR switches are ideal for machinery because when the tool is plugged in, no matter the on/off switch's position when it was turned off, the machine will not start until the "on" button is deliberately pushed.

You can imagine the potential for carnage if, for example, a bench saw was left switched on and was simply turned off at the wall, then someone comes along and turns the wall switch back on (or plugs it in) without checking the switch status, and the thing starts up. NVR switches prevent that from happening.

A further safety accessory on some NVR switches is a wide plastic paddle that hinges at one end of the switch housing and rests above the "off" switch. This means that if you need the machine to stop, you can just bang on the paddle. Because it is much larger and far more visible than the actual off button, it is much easier to find and requires less physical accuracy to shut everything down in an emergency.

Therefore, I consider an NVR switch a worthwhile upgrade to any machine (and clearly, so did my dad).

Four screws held this switch's mounting panel to the body of the drill press. Immediately after pulling the panel away, I could see a problem; one of the wires was hanging literally by a thread. Unfortunately, the thread was not a conductive strand of wire, but a piece of the fabric wire insulation trapped under the terminal.

This almost certainly accounted for the lack of motor power, and explained why the lamp, which is switched separately, still worked.

The problem I had now is that these wires were very short and I had almost nothing spare with which to re-terminate the wire. I traced the wire back through the body of the drill press to where it connected to the motor, and noted that it was part of a bundle that shared an insulation sleeve. Pulling a single wire through wasn't a problem, but putting one back through could be.

I ended up soldering a new length of wire to the existing one and simply pulled it all through until the old one

was out, and I had two new ends in place, ready for the terminals.

After connecting the terminals to their respective lugs, I plugged in the mains cable and with no belts engaged, tested the motor. It spun up and ran smoothly. Reassembly was a doddle, and the machine is ready for another 30 years of no-doubt reliable service.

The (intermittent) return of the UPL audio analyser

A. L. S., of Turramurra, NSW, ran into an odd problem in an expensive piece of test equipment. And unfortunately, it was one of those dreaded intermittent faults. Luckily, he managed to fix it, and saved thousands of dollars in the process...

I purchased a second-hand Rohde & Schwarz UPL DC-110kHz audio analyser a few years ago, at a fraction of its original price (which is in the tens of thousands).

In the June 2018 issue (pages 62-63; siliconchip.com.au/Article/11104), I described the problems that I had with it due to its CR2032 memory back-up battery going flat and the difficulty in finding and replacing that cell. After that, it worked really well, until recently, a new and rather strange problem emerged.

Now and again, this device would start up as usual, pass the self-test and revert to its previous test setup. But the image on the screen was inverted! The image was beautifully bright, with accurate measurements displayed, but you would have to stand on your head in front of a mirror to read it! Eventually, if left to warm up, the display would come good.

This analyser was a real find because it had eight factory options, including low-distortion generators, jitter and interface tests and mobile phone acoustic testing analysis. Its specs are really impressive, and it analyses an incredible array of audio signals, including digital audio signals.

As you would expect for this type of fault, it grew worse over time, and the screen would sometimes invert unexpectedly. It became annoying when setting up audio tests because I had to wait some time for it to warm up before I could use it.

Looking in the "basic" UPL operating manual, which is 462 pages, I could find nothing concerning this fault. I couldn't even find a service manual on the internet, which was discouraging. But because of its relative youth and its complexity, I decided to approach Rohde & Schwarz again for repair.

I rang them first to see if it was repairable in Sydney because they are very close to my home, but they said that this was not possible. They would have to send it off to Germany to get a quote, and this would cost approximately $1400, with no guarantee that it could be fixed. To make matters worse, I was told that this instrument was no longer supported, and parts may not be available.

I'm not complaining though; I understand that they are just trying to cover their costs. This is one of the most complex instruments I have ever used.

Anyway, I wasn't going to spend that much money just for a quote, so I soldiered on despite this fault, until one day it dawned on me to see whether printing the screen when it was inverted would show the same fault.

As it happens, the instrument has a parallel output port. I have a device called "Print Capture" which I connected to a small laptop on top of the instrument, to save screen dumps.

I figured if it still printed screenshots correctly when the display was mirrored, that might give me a clue as to the origin of the fault. So, I waited for the fault to appear, then quickly pressed the hardcopy button. Unfortunately, during the two-minute download, the fault disappeared. So I had to wait again for the fault and do it all over again. Finally, the hardcopy printed, with a perfect image!

That meant that the fault was downstream of the CPU and must be between the mainboard and the screen.

I then had another idea – to connect a screen to the VGA port on the instrument. If that worked, perhaps I would not have to worry about the screen inverting on me in the middle of a test.

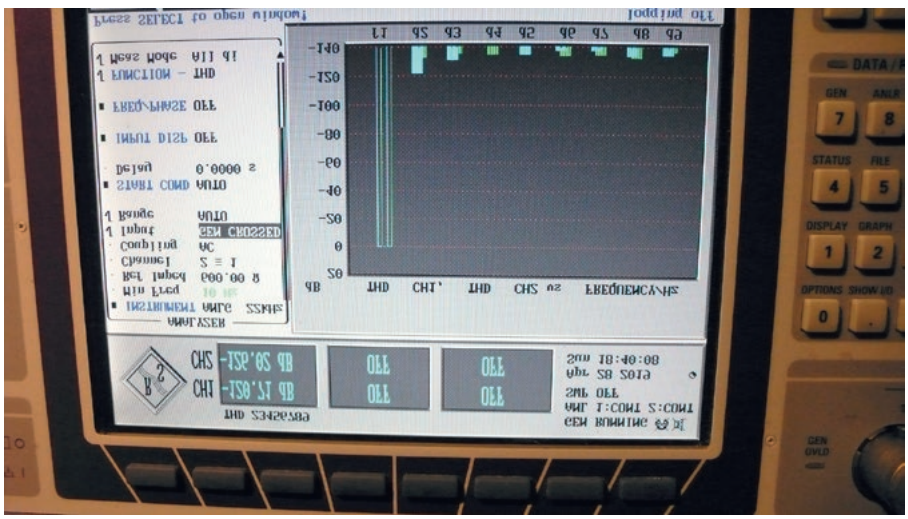
All I could find in the workshop at that time was a small Panasonic television with a VGA input, so I set that up. When the fault eventually re-appeared, I fired up the monitor and got a perfect image on the screen. This meant that at least I could use the instrument without interruption, but it was a bit unwieldy because the TV was big and difficult to mount.

These symptoms confirmed that the fault was not on the mainboard nor the CPU and must be isolated downstream to the display screen and its associated circuitry.

I then developed a plan to remove the front panel assembly, so I could take out the suspect screen and get the part number from it. I would then buy a new screen and replace it, and hopefully, that would fix it. If the fault still existed, I would then need to trace the fault back to the PCB which fed the display.

This seemed like a good plan, but it did not go smoothly. For a start, the front panel was an integral part of the chassis, and I had to undo lots of screws to remove it.

Then I found that there was a brittle ribbon connector that I was very reluctant to remove, meaning that I could not completely remove the front assembly without doing some permanent damage.



The UPL audio analyser initially displayed the screen inverted when turned on, but would return to normal after 'warming' up.

Thirdly, Rohde & Schwarz had thoughtfully removed the part number from the back of the screen, so I could not buy a new one with confidence.

So rather than cause any permanent damage to an instrument which was working well, I decided to backtrack and put it all back together, and just resigned myself to using it with an external monitor.

In doing so, I noticed that one of the connectors I had to plug back in was sticky, so I pushed it home, and it clicked in beautifully with the retainer clips. But then I remembered that one of those clips was only halfway engaged when I disconnected it.

Putting it all back together was tricky because there was an Earthing spring shaped like a hairclip. I cleaned this to make sure it would make good contact, but it had to be held in place while some screws were inserted. Each time I tried to do this, the screws were flung out all over the floor. But I persevered and eventually got it all back together.

This is such a delicate, complex and expensive instrument and I was very nervous about powering it back up, but it came up OK, with a normal screen. And it has never inverted since! A miracle?

This left me a bit puzzled. Was the fault due to that connector not being locked in properly? Or perhaps cleaning the Earth spring helped? All I know is that I am happy to have it working correctly again.

In retrospect, I realised that this problem sometimes occurred when there was some vibration in the workshop. I also remember it happening when some of the buttons on the front panel were pressed. So I suspect that the Earthing comb had tarnished and was occasionally losing contact and upsetting the display.

RF interference at the end of the rainbow, part deux

Regular readers of "The Serviceman's Log" may recall the story from D. P., of Faulconbridge, NSW in the May 2019 issue (p64). It was about a pager signal that was producing interference on amateur radio VHF frequencies in the Blue Mountains, NSW. They managed to track down the source and get it fixed. Now he's at it again...

Encouraged by our success with the pager interference problem, Blue Mountains Amateur Radio Club members decided to tackle another interfering signal which had been bothering us for quite some time. This interference was again on the amateur VHF (2m) band.

It no longer triggered our repeater since the repeater had been fitted with a tone squelch system, but it did disrupt its operation while it was actually in use. It also interfered with simplex operations, and with the reception of other repeaters on the band.

The interference took the form of a strong carrier modulated with a noisy, randomly varying and hum-infested audio tone. There was no discernible pattern to the signal, and the modulation seemed to be a mixture of AM and FM. The signal drifted up and down the VHF Amateur band, sometimes disappearing for hours at a time, only to return later.

Monitoring the signal with a general-coverage VHF receiver, we found that during the times it was absent from the amateur band, it had merely drifted into other bands, potentially causing problems for other services. As far as we could tell, the signal was present 24/7, moving around the VHF spectrum seemingly at random.

Various services in the Mountains use VHF communications, including aircraft working on rescues and bush fires, and the Rural Fire Service and the National Parks and Wildlife Service, during bush fires and search-and-rescue operations. This signal could potentially interfere with these activities.

This interference could be heard over a wide area, with widely varying signal strength, giving no clue to its location. Attempts to triangulate the source had produced inconsistent results, with bearings that did not intersect.

The technique I had used with the pager interference, of monitoring the signal in my car while going about my normal activities, was impractical in this case because a second operator would have been needed to keep the receiver tracking the interfering signal as it drifted in frequency.

Our first thought was that the culprit could be a 'dirty' switch mode power supply (SMPS), but it was detectable over a much larger area than could be accounted for by a single device. Could it be an SMPS propagating over a wide area by being conducted over mains power lines? That seemed a bit unlikely.

Another idea was that this could be something to do with the railways. The Blue Mountains are crisscrossed by "traction feeders": large three-phase power lines which feed rectifiers, situated in sub-stations in various locations throughout the Blue Mountains, to provide 1500V DC for trains. This is an extensive, heavy-duty network, a legacy of the days when electric goods trains operated on the Mountains.

Electric locomotives were abandoned some years ago in this area in favour of diesel-driven locomotives. A bad idea, it seems to me! The electric locomotives, when travelling down the Mountains, used regenerative braking, which put enormous amounts of power back into the network.

It was said that a good proportion of Sydney's passenger network could be run by the regenerative power from a goods train with a full load as it drove slowly down the Mountains.

Anyway, our club was keenly involved in "fox hunting", so many of us were kitted out with mobile yagis, receivers with input attenuators, "sniffers" (small hand-held receivers which are used in the final stages of locating the "fox") and various other bits and pieces.

I should point out that in the Amateur Radio fraternity, "fox hunting" refers to the activity of searching for hidden transmitters. It does not typically involve horses, packs of dogs, pink coats or hunting horns!

Without any better ideas, we decided to have another crack at triangulating the signal. We thought that the previous inconsistent results could have been due to propagation changing as the signal frequency drifted, because of probable multi-path phenomena, so we decided to try taking bearings only when the signal was around a particular frequency and only from the highest locations we could find.

Several cold and lonely vigils were spent on top of wind-swept mountains, waiting for the signal to drift into range; a bit like fishing, I suppose!

We began to get more consistent results. At least the bearings now intersected, but the intersection was in rugged bushland, well away from developed areas.

We were somewhat doubtful that this was correct, but we had been quite careful and had repeated the triangulation several times, so maybe it was right.

The topographic map showed a

pumping station near our target area. This seemed like an unlikely source, but we decided to investigate further.

We drove towards the target area as a small group, monitoring the interfering signal as we went. We found ourselves on a road that passed through a group of houses, and beyond the last house, headed into the bush, towards the area indicated by our triangulation. The signal here was very strong, and the direction indicated by our equipment was straight ahead along the road.

We noted a heavy-duty three-phase power line and a large diameter water pipe running alongside the road, so it looked like we were on the right track. Eventually, we arrived at the pumping station.

As luck would have it, there were vehicles parked outside, and people were working in the building. The interfering signal was now extremely strong. It had to be coming from the pumping station.

We approached the people working in the building and spoke to their supervisor. He seemed quite suspicious of us and our gear, and asked us if were ghost hunters or UFO enthusiasts! We told him that we were not nearly as exotic as that, just ham radio operators trying to track down some radio interference.

When we let him hear the interfering signal and demonstrated our directional antenna, he seemed quite interested and became less suspicious; friendly, even. He invited us into the building and gave us permission to look around.

Using a sniffer, we established that the signal was incredibly strong around a box mounted high on a wall in the building.

The box had no visible label or markings, had a power lead and what appeared to be a telephone cable going into it, and a coax cable which disappeared into the ceiling. It seemed odd that it was mounted in such an inaccessible position.

There was a great deal of RF emanating from the box, possibly due to a bad coax shield connection, or even something as simple as a loose coax connector. But we were not in a position to touch anything, and had to content ourselves with speculation.

Our new friend and his crew (who by now had also become quite interested in what we were doing) said they had no idea what the box was, and that as far as they could remember, it had always been there.

We demonstrated to them that a strong interfering signal was coming from it, and pointed out that whatever was in there was probably malfunctioning and not doing its intended job.

We asked him if he would turn its power off temporarily to confirm that it was the source of the interference. This he did, whereupon the interference immediately stopped.

Apparently, we had done a good enough job of convincing him that we were not insane and that we knew what we were talking about.

He declared that he was going to leave it turned off until he could find out what it was, who was responsible for it, and get some maintenance done on it! The interference has never returned. What was in the box remains a mystery.

LED lamp repair

L. B., of Mittagong, NSW got fed up with modern globes which don't last anywhere near as long as they are supposed to. Having had two fail in quick succession, he decided to open them up and take matters into his own hands...

The life expectancy of mains-powered LED lamps can be far less than stated on the packaging. Some time ago I purchased four Mirabella lamps from the supermarket at half price and they worked just fine for a while. I used them 'base up' in lamps in my workshop, and after about five months the first one failed – it started flickering when switched on and then went dark.

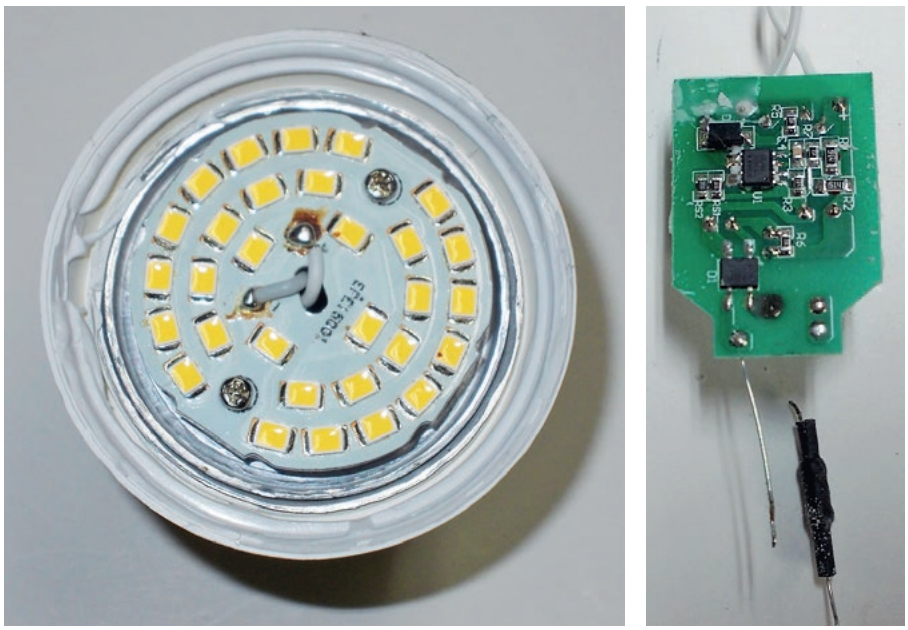
I swapped it for another and put the failed one aside until I had time to explore why it had failed so soon. Then a little while later, the second one failed in a different light fitting. I decided it was time to open them up and see what was going on. I was able to cut off the diffuser housing quite easily using a hobby knife, by slicing through the silicone attaching it to the base.

Under the diffuser I found one LED array, held to a heatsink using two screws. I marked the circuit board with which wire connected where and then unsoldered them.

Removing the two screws allowed the removal of the circuit board. The heatsink was a press fit into the internal metal body and when removed, it exposed the power supply board, encapsulated in more silicone.

Carefully removing the silicone with the hobby knife and pliers then desoldering the wires from the bayonet base allowed me to remove the power supply board.

Removing the remaining silicone from the base exposed two slots on the sides of the base for locating the circuit board. Both power supply boards had an off-board 10Ω resistor which had desoldered itself, hence the failure of the lamps. The area where it used to be soldered to the board was burnt in both cases, apparently due to a lot of heat being produced.



Right: the power supply board for the LED lamp, with an external 10Ω resistor shown in black below.

I assume that the heat from the resistor (encapsulated in the silicone) did its dastardly deed on the connection to the circuit board. Or maybe the original solder joint was not good, resulting in high resistance and therefore heating of the joint.

I reattached the resistor to the board after cleaning away some of the solder resist and applied a much larger amount of solder. Refitting the circuit board without the silicone encapsulation seems to have fixed the problem as neither of these LEDs has failed again, after being in service for longer than they were when they failed. Anyway, I guess time will tell.

LED motion light modification

G. P., of North Rocks, NSW didn't fix something that was broken, but rather, modified the circuit because it didn't do exactly what he wanted. While not strictly servicing, it does show that you can alter some commercial devices to provide the exact functions that you require...

Our double-level unit has a dark staircase passage. As the light switches for this area are located away from the staircase, we purchased some motion-activated battery-powered LED lights. They work well but due to the long minimum light on-time, the three AA cells in each do not last long. So I decided to investigate whether I could shorten that on-time.

I took one unit off the wall and opened it. I found that it uses a BISS001 IC ("Micro Power PIR Motion Detector"). I used Google to find and download its data sheet.

This was very helpful. I discovered that the time duration (Tx) during which the output pin (Vo) remains high after triggering depends on the RC circuit (R10 and C6) connected to pin 3 (Tx = 24576 × R10 × C6). I compared this to the unit, and found that R4 and C2 corresponded to the R10 and C6 described in the data sheet.

I timed the minimum on-cycle at approximately 33 seconds, but we required 15-20s. On the board, R4 was 150kΩ, so I determined that I should roughly halve its value by replacing it with a 68kΩ resistor.

But after replacing this resistor, I found that the on-time was only a few seconds shorter. After testing a few different resistor values, I found that a 62kΩ resistor gave an on-time of about 19 seconds. That was good enough. Perhaps there is a leakage path in the circuit which can alter the time constant.

Induction cooktop repair

R. S., of Moruya, NSW, has become something of an expert on the workings of induction cookers after performing several repairs on these finicky devices. But he seems to have figured out how to solve the reliability problems he's encountered, as explained below...

Induction cookers work by converting 50Hz mains power to a higher frequency, typically 20-40kHz, and applying that to a flat coil of heavy wire which sits under the glass "hotplate" of the cooktop.

The ferromagnetic pan (only this type will work) then acts as the secondary of a transformer, being heated by the combination of eddy currents and magnetic hysteresis losses.

Current to the coil and thus heat is controlled by an IGBT (insulated gate bipolar transistor). The IGBT control circuitry incorporates a timer function and temperature control and also prevents operation if there is no suitable pan on the cooktop. An excellent description of the operation of this type of circuit is at: **siliconchip.com.au/link/ab13**

I bought my first portable induction cooktop in early 2016 but it failed dramatically and noisily when first switched on, taking out the switchboard circuit breaker. I returned it for a refund.

Later in 2016, I was given a Baumatic BHI100 portable cooktop which worked very well for nearly a year before failing in a similar manner to the other one. I claimed a replacement under warranty and this was duly supplied but the replacement then failed after a few weeks. I claimed another refund under warranty, but heard nothing back.

As I seemed to have little to lose, I disassembled one cooktop, which seemed to be well made, and hence possibly worth repairing. I identified a blown 12A fuse and a short-circuit IGBT, type H201353, rated at 1350V and 20A.

My experience is that the failure of a main power supply component often causes failure of several other components but as the new IGBT and fuse were inexpensive, I decided to try replacing both and see what happened. I decided to up-rate the IGBT using an IHW30N135R3, rated at 1350V and 30A. Somewhat to my surprise, this fixed the fault entirely.

Heartened by this success, I then disassembled the other failed cooker and found a blown 12A fuse, a faulty IGBT and a short-circuit bridge rectifier. I replaced the bridge rectifier with a higher rated unit, a GBJ2510 rated at 1000V, 25A. The fuse and IGBT were also replaced, as before, and again this fixed the fault.

I had three subsequent failures but new IGBTs fixed these faults. For the latest replacement, I used the highest rated TO-247 "TrenchStop N-Channel" IGBT that I could find, an Infineon IHW30N160R2, rated at 1600V, 60A. Touch wood, but they have not failed since.

In the Baumatic unit, the bridge rectifier and IGBT are mounted on a heatsink on the main circuit board. The unit is easily disassembled; plugs and sockets interconnect the individual boards. Replacing the rectifier and IGBT only required basic soldering and de-soldering skills but of course, as with any mains-powered device, caution is needed.

As an IGBT failure does not seem to take out other components, and the devices are not that expensive, it is generally worthwhile for reasonably experienced and cautious people to have a go at fixing similar units.

The designers could perhaps have used more robust semiconductors. It is asking a lot of a relatively small TO-247 component, even in so-called "resonant switching mode", to deliver 2000W. There may be other faults in the design. This model of Baumatic portable cooktop does not seem to be available now, except as a clearance item. SC

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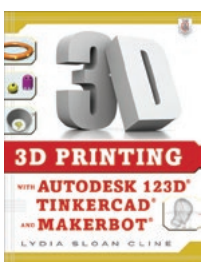

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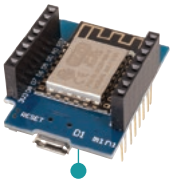

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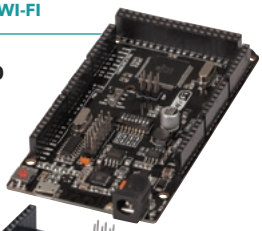

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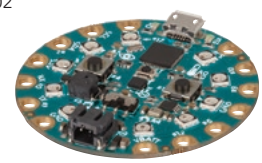
Add dazzling effects and control your e-wearable project or costume. 10 Mini RBG LEDs. Accelerometer. Microphone and more! XC3920



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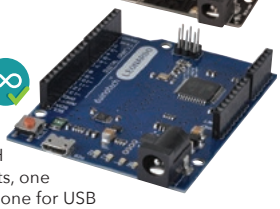
LEONARDO

Most of the DuinoTECH models use two chipsets, one for the main controller, one for USB communication. Now you can have your DuinoTECH Lite emulate a computer keyboard, mouse, joystick and many other types of input device. XC4430



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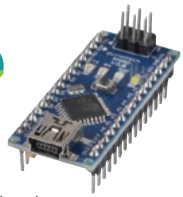
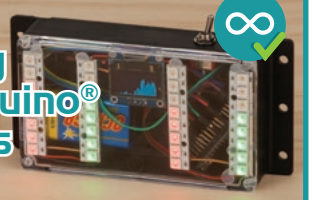
NANO BOARD

Small in size, but packs virtually all the features of the full duinotech boards into a tiny DIP-style board that drops directly into your breadboard.

• ATMega328P microcontroller

XC4414





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We have a compilation of projects, ready to build with parts from our range.

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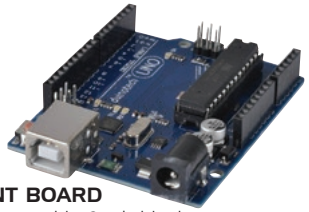

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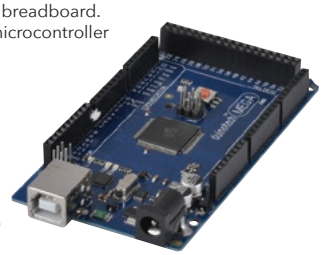

MEGA EXPERIMENTERS KIT

MEGA EXPERIMENTERS KIT

Contains a Arduino-compatible MEGA main board, a breadboard, jumper wires and a plethora of peripherals in a plastic organiser. See website for details. XC4286

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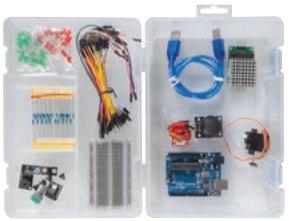

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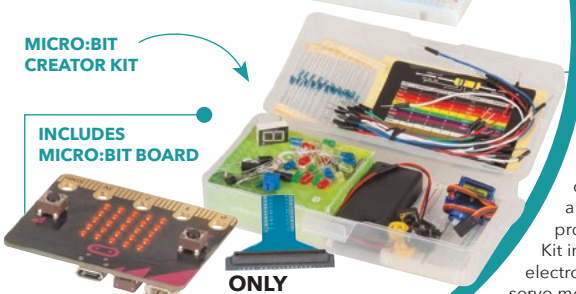
INCLUDES MICRO:BIT BOARD



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PLUS 36-PAGE INSTRUCTION GUIDE

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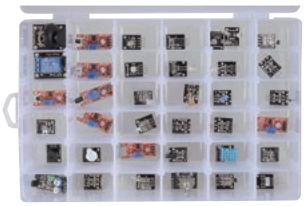

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Includes commonly used sensors and modules for Duinotech and Arduino®: joystick, magnetic, temperature, IR, LED and more. Packaged in a clear plastic organiser. XC4288 See website for details.

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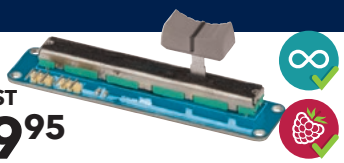

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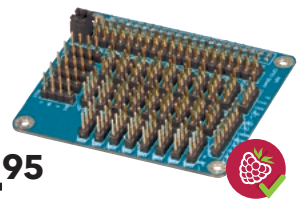

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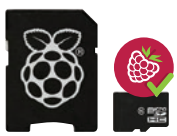

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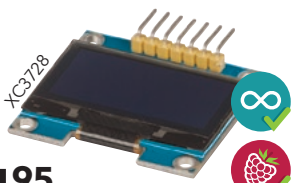

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Let the games begin with these exciting retro arcade consoles. Simply install a Raspberry Pi 3B+ (XC9001 **$89.95** Sold Separately), into the console, insert a Retropie installed micro SD card (XC9031 **$24.95** Sold Separately), copy over some games and you are ready to play.

See website for detailed install instructions.

RETRO ARCADE GAME CONSOLE
- Connects to your TV, computer or projector with HDMI or VGA cable
- 2 Player console

XC9062 **$169**

10" SCREEN RETRO ARCADE GAME CONSOLE
- Includes a joystick and 6 buttons.
- Built-in speaker

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XC9064

RASPBERRY PI 3B+
(XC9001 **$89.95**)
Sold Separately

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DIY GAME CONSOLE BUILD-A-GAME LEARNING KIT

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SNES layout. Features A/B/X/Y buttons, start, select, and direction controls. Easily configurable, USB powered. XC4404

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Perfect for building a Raspberry Pi 3/3B+ based emulator.
- HDMI, 3.5mm, and micro USB (power) access
- USB Ports: 4 (Standard, Type -A)

XC4403

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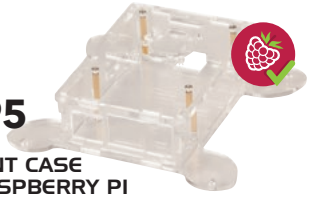

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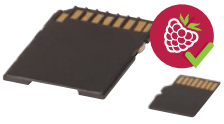
VESA MOUNT CASE TO SUIT RASPBERRY PI

Mount your Raspberry Pi 3B+ securely to the back of your monitor or TV.
- 100 x 100mm VESA mounting holes
- Perspex
- Includes mounting screws

XC9003



RETROPIE OS ON SD CARD FOR RASPBERRY PI

Preloaded with RetroPie, and auto-installs when used for first time.
- 16GB microSD card
- Supplied with an SD card adaptor

XC9031

Note: Best compatible for Raspberry 3B/3B+

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POWER SUPPLY FOR RASPBERRY PI

5.1V 2.5A. Use with Raspberry Pi 3/3B+, charge power banks, etc. 1.5m lead with micro USB connector.

MP3536

GAMING CONSOLE TOOL KIT - 26PCE

Everything you need to get into your console and accessories.
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Extra Satellite Module
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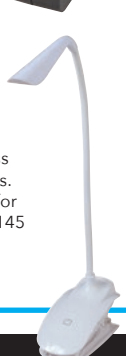

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DC9053

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- Suits digital radios with antenna input
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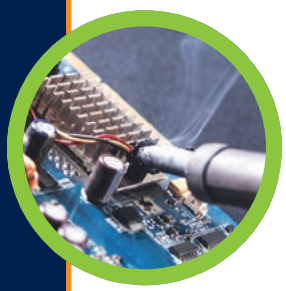

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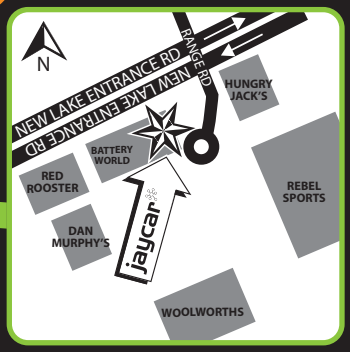

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Covid-19 "virus" malware can be *deadly* for computers

As if we didn't have enough to worry about with coronavirus for humans, so far there have been five malwares identified which have the ability to do serious damage to your PC.

As reported by ZDNet.com early in April (no, not April 1!), one of these can not only trash your PC files but also rewrite your computer's master boot record (MBR).

While an expert with the right software should be able to restore the MBR and files, it will take time and could be very costly.

ZDNet report that some of the viruses appear to be malware, demanding payment for the "cure" – which may not even exist.

For much more information, visit the ZDNet website: siliconchip.com.au/link/ab12 *SC*

New w-i-d-e-b-a-n-d RTL-SDR modules

In the November 2017 issue we reviewed a low-cost RTL-SDR kit from Chinese firm Banggood Technology. Since then, fully assembled RTL-SDRs have become available from Banggood and other Chinese suppliers. So we decided to put them through their paces.

We described how software-defined radios (SDRs) work in our May 2013 issue (siliconchip.com.au/Article/3778), and gave details on using the popular SDR# ("SDR-sharp") software.

Then we followed that up with an up-converter project for low-frequency reception in the June 2013 issue (siliconchip.com.au/Article/3810).

That design was then expanded into the SiDRADIO integrated SDR, which was described in the October-December 2013 issues (siliconchip.com.au/Series/130).

And, as mentioned in the intro, we reviewed the $30 Banggood SDR kit in November 2017 (siliconchip.com.au/Article/10879).

So we won't go back over all the details of how SDRs operate. If you want the full treatment, read the May 2013 article. But for those who just need a quick refresher, let's go over the basic details.

A software-defined radio is essentially a device capable of converting a PC into a radio receiver, tuned and controlled by software running on the PC.

"RTL-SDR" refers to an SDR based on a Realtek RTL2832U digital demodulator chip, usually in conjunction with a multi-band VHF/UHF tuner chip like the Rafael Micro R820T2.

The first products using devices like the RTL2832U and the R820T were low-cost DVB-T dongles, released around 2009 to provide a cheap way to receive digital TV with a PC.

It was only a little later that people realised that the same dongles could be used to receive AM, FM, CW and SSB radio signals. That was the birth of low-cost SDRs.

The Banggood SDR kit we reviewed in 2017 was claimed to provide wide range reception from 100kHz to 1.7GHz.

It turned out to be rather tricky to assemble, but gave quite respectable performance even on the LF-HF

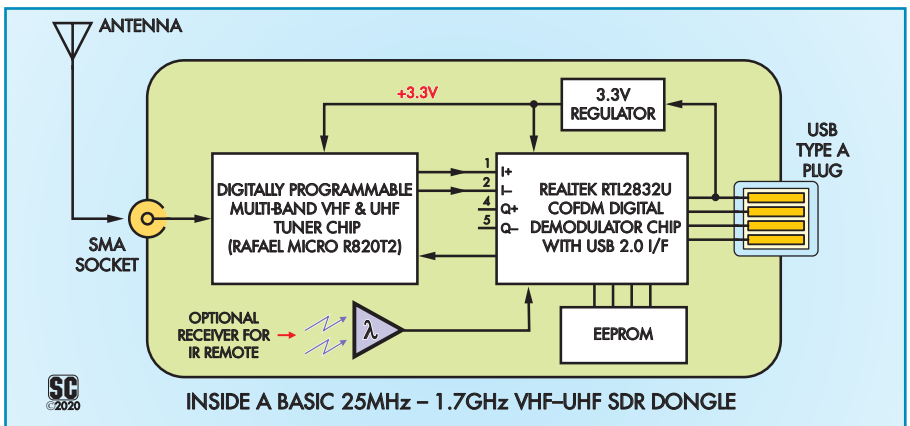


Fig.1: the configuration of a basic RTL-SDR dongle. The R820T2 provides preselection and RF gain, while the RTL2832 converts the RF signals to digital data, to feed to the PC via its USB port.

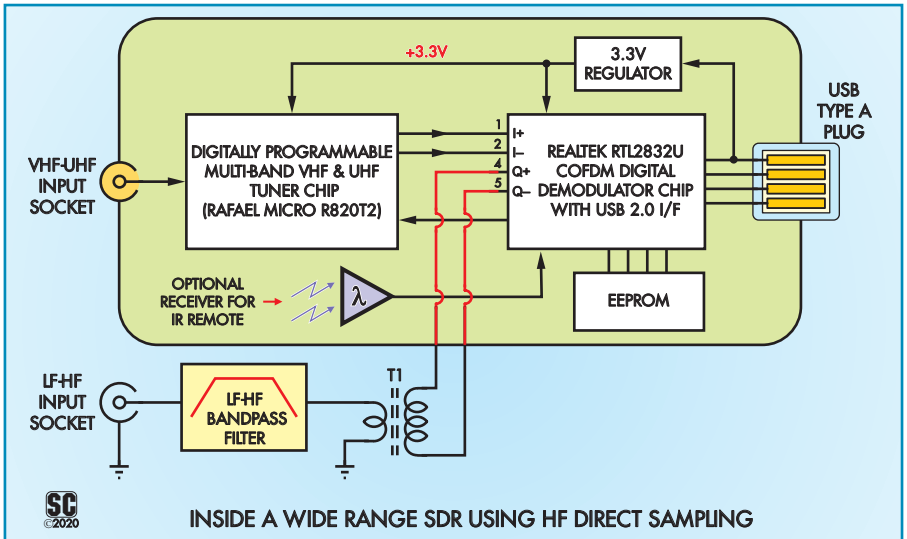


Fig.2: an SDR dongle like that shown in Fig.1, but modified to provide LF-HF reception using direct sampling. The lower frequency signals are fed to transformer T1, which couples them to the RTL2832's Q+ and Q- pins for sampling.

bands, despite using the cheaper 'direct sampling' approach rather than an upconverter.

Since then, Banggood and various other Chinese suppliers have come up with several new fully-assembled RTL-SDR units, and they are what we are investigating in this article.

A basic RTL-SDR dongle

Fig.1 shows the block diagram of a basic RTL-SDR dongle. The main components are a Realtek RTL2832U COFDM digital demodulator chip and a Rafael Micro R820T2 digitally programmable multi-band VHF and UHF tuner chip.

The RTL2832U chip includes a USB 2.0 interface which receives commands from the PC software and also feeds the demodulated signal samples back to the PC.

It also includes the core of an 8051 CPU and a hardware FIFO to handle the bulk USB transfers.

Fig.1 also shows an infrared receiver. This is basically a carry-over from the original use of these dongles for DVB-T reception (to receive signals from a remote control), and isn't needed for SDR operation.

The R820T2 chip is only able to receive signals between about 25MHz and 1.7GHz (1700MHz), so the basic RTL-SDR dongle is limited to VHF and UHF reception.

While there are many signals on these bands, there are also plenty on the LF and HF bands below 25MHz. Some additions are needed for RTL-SDR reception on these lower bands.

Direct sampling

The cheapest way of adding LF and HF reception capability is shown in Fig.2.

Here, the LF-HF signals are fed into the SDR via a second input, then passed through a bandpass filter to reduce interference from signals outside this range. Then they go through a small RF transformer (T1) and into the Q+ and Q- inputs of the RTL2832U demodulator chip. These pins are not used for VHF/UHF reception.

So, these signals can be received by the PC software directing the RTL2832U to perform direct sampling from the Q+ and Q- pins, rather than from the I+ and I- pins. So changing between VHF-UHF reception and LF-HF reception can be done by software command.

With this approach, the LF-HF signals receive no input gain or preselection.

As a result, the sensitivity and selectivity of this type of 'wide range' RTL-SDR on the LF-HF bands is not marvellous – although it can be acceptable for some applications.

Some of the newer RTL-SDRs using the direct sampling approach have a

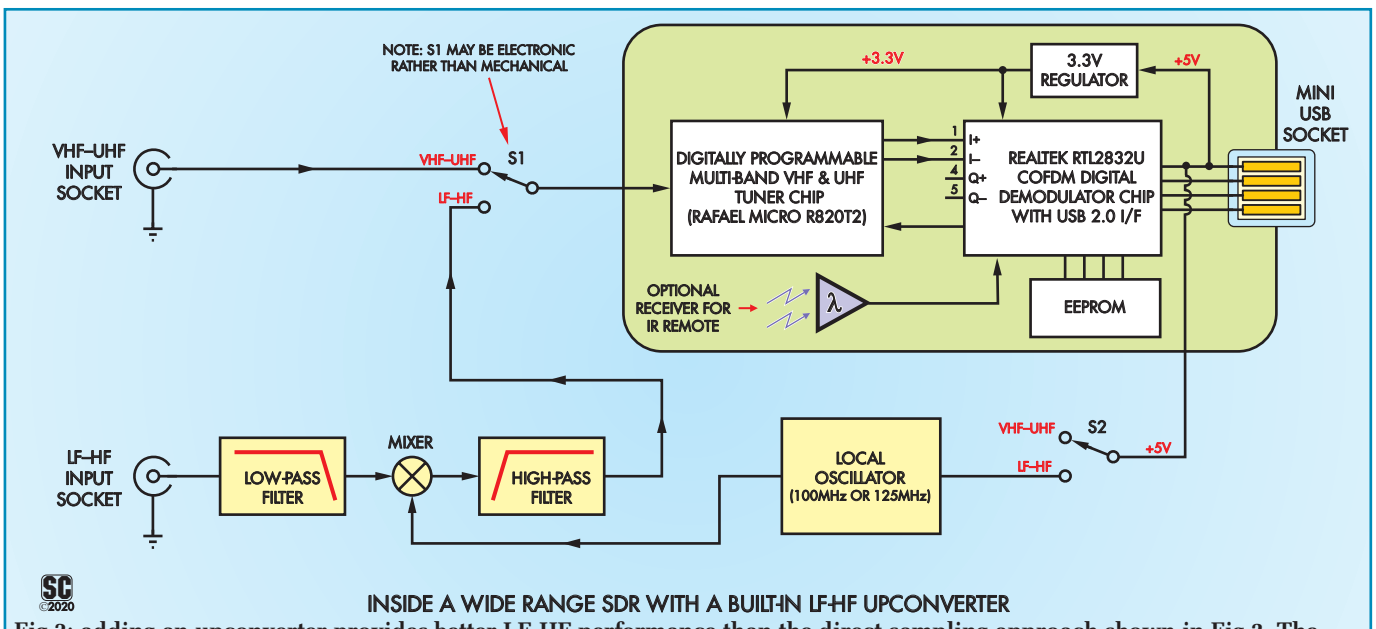
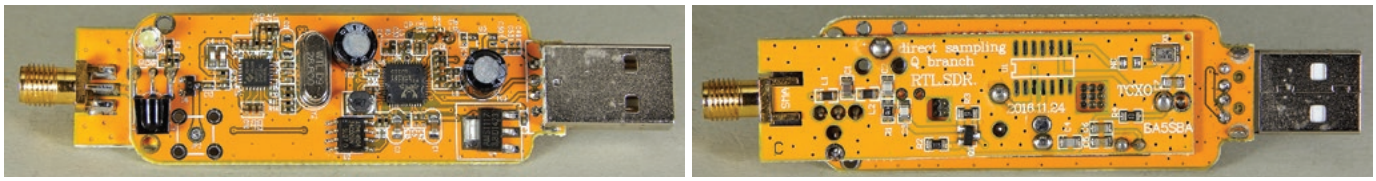


Fig.3: adding an upconverter provides better LF-HF performance than the direct sampling approach shown in Fig.2. The LF-HF signals are mixed with a much higher frequency local oscillator signal, and the resulting sum-product (a higher frequency again) is fed to the SDR's UHF input via a high-pass filter that rejects the unwanted signal components from the mixer.



Internal front and back views of the "V3" RTL-SDR, showing board construction and the SMA and USB sockets on each end (the SMA is the input and USB the output). The upper board (left) is identical to the old DVB-T dongle.

single RF input socket, with a 'diplexer' filter used to separate the incoming LF-HF signals (<24MHz) from the VHF-UHF signals (>24MHz).

At least one also provides a 10dB RF preamp in the LF-HF branch, to compensate for losses in the bandpass filter and T1.

We'll look at this unit shortly.

The upconverter option

The upconverter approach provides improved reception below 25MHz. This is shown in Fig.3.

The LF-HF signals again come in via a separate input socket, but they then go through a low-pass filter to attenuate any signals above 25MHz which could cause interference. Then they are fed into a mixer, along with a local oscillator (LO) signal, typically either 100MHz or 125MHz.

The mixer output incorporates the sum and difference frequencies. It goes through a high-pass filter, with its corner frequency set to be a little above the local oscillator frequency.

This removes the original, local oscillator and difference signals, leaving only the sum signal.

So the output from the high-pass filter is effectively the incoming LF-HF signals shifted up by the local oscillator frequency.

With a 100MHz LO, an incoming signal of say 200kHz becomes a signal of 100MHz + 200kHz or 100.200MHz, while an incoming signal of 8.35MHz is shifted up to become a signal of 108.35MHz, and so on.

Switch S1 selects either the VHF-UHF signals from the upper input socket, or the upshifted LF-HF signals from the mixer and high-pass filter. This can be either a mechanical or an electronic switch.

Switch S2 at lower right is used to control the operation of the local oscillator, switching it on for reception of LF-HF signals, or off for reception of VHF-UHF signals.

This upconverter approach is more complicated and expensive than the direct sampling approach, but it does deliver somewhat better reception for LF and HF signals.

That's mostly because the upshifted signals go through the same R820T2 digitally-programmed multi-band tuner as the VHF and UHF signals.

The fact that the SDR is receiving LF-HF signals at a higher frequency than they are broadcast is taken care of by the reception software (eg, SDR#). These packages have an option to allow the effective (and displayed) tuning frequency to be shifted up or down by any desired figure.

So if your upconverter has a local oscillator frequency of 100MHz, all you have to do is instruct the application to subtract 100MHz from the upshifted frequency, and it will be shown at the correct frequency.

The main shortcoming of the upconverter is that the added local oscillator degrades the tuning stability, unless it has exceptional frequency stability. In other words, the LF-HF tuning tends to 'drift' or 'wander' with temperature variations.

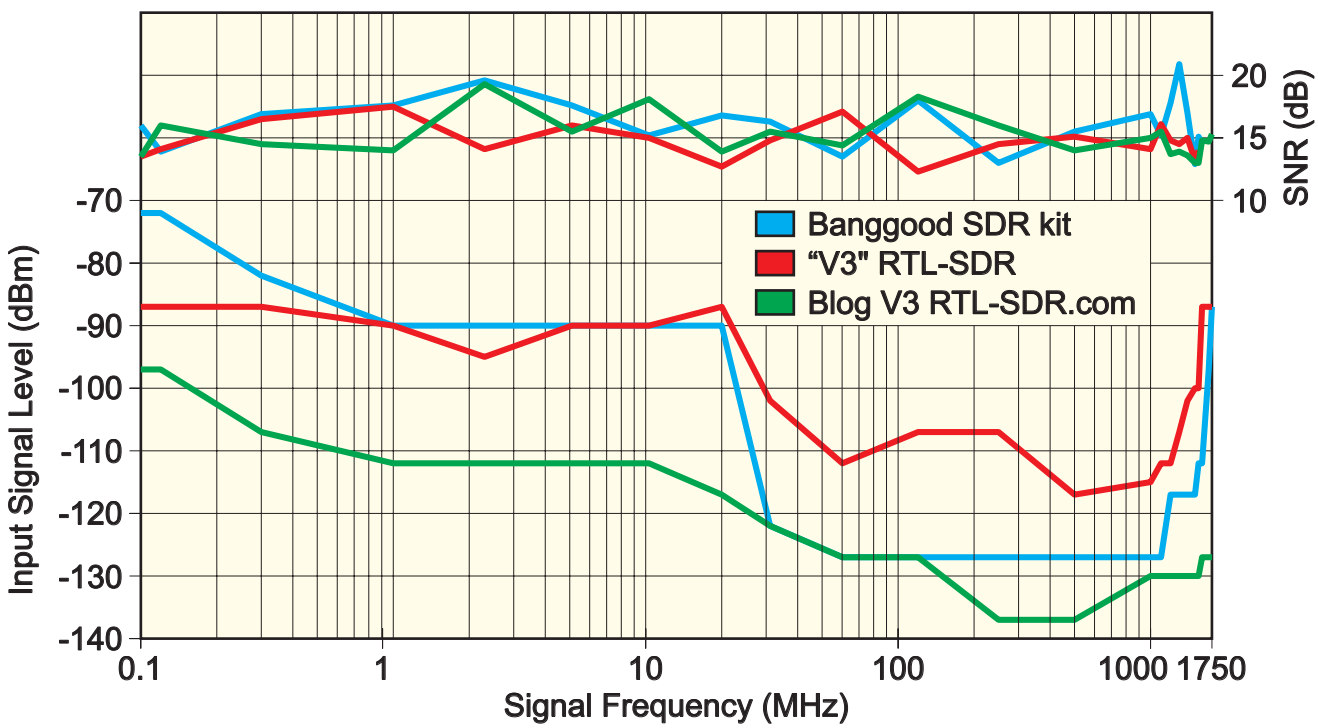
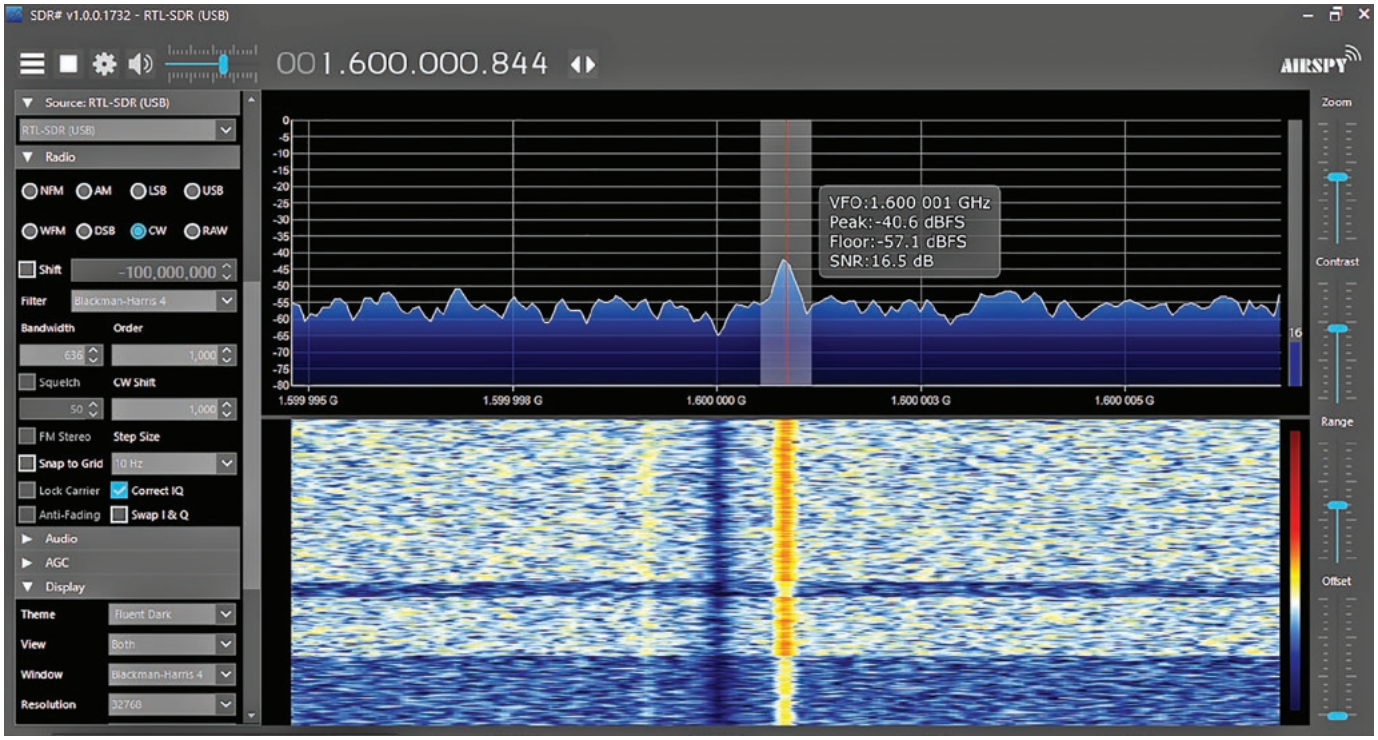


Fig.4: the sensitivity and signal-to-noise ratio figures for the reception of a range of frequencies from all three direct-sampling SDR units mentioned in this article. Note that the SNR (signal to noise ratio) figures are all very similar.



SDR# grab: A screen grab from SDR# showing the performance of the RTL-SDR Blog V3 dongle when receiving a 1.600GHz CW signal at -127dBm (100nV). The received signal-to-noise ratio is 16.5dB – pretty impressive!

That's why upconverter type RTL-SDRs generally claim to contain a high stability TCXO (temperature-controlled crystal oscillator), with a stability of say ±0.5ppm (parts per million). With a 100MHz local oscillator, that corresponds to a drift of ±50Hz.

The other shortcoming of the upconverter approach is that because it doesn't provide the incoming LF-HF signals with any preselection, strong signals near the signals you're interested in can cause overload in the upconverting mixer, resulting in interference.

Luckily, this can be remedied by using an external RF preselector ahead of the LF-HF input of the SDR.

In the remainder of this article, we'll look at RTL-SDRs that use the direct sampling approach. Next month, we'll describe other units that use an upconverter.

A compact "V.3" RTL.SDR

Currently, you'll find quite a few low-cost RTL-SDRs available on the web. Many of them come in a compact aluminium case measuring 74 x 25 x 15mm, with a USB type-A plug at one end and an SMA input socket at the other.

Basically, these are an improved version of the original DVB-T dongles, with the metal case offering better electromagnetic shielding than the old plastic cases, and the SMA input socket offering better matching at UHF than the old Belling-Lee (PAL-type) sockets.

A typical example is shown in the photos below. This one came from Banggood, and cost A$30.16 delivered, including insurance and GST.

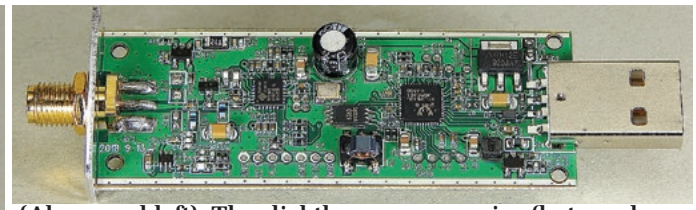
It came with a short USB cable to connect it to the PC, and it carries the RTL.SDR label, together with a small "V.3" legend at the input end.

It seems to be a clone of another similar looking unit sold online by RTL-SDR.com (**www.rtl-sdr.com/store**) and various agents. The latter unit carries the label RTL-SDR.COM, and we'll discuss that one shortly.

If you open up the first unit, you'll discover that it's built on two small PCBs which are stacked, one on top of the other (see photos opposite).

The upper PCB appears to be one of the original DVB-T dongle boards,

The RTL-SDR dongles are supplied in metal cases, which assists in shielding from interference. This is the cheaper of the two units reviewed here – compare this to the higher-performing unit shown above right.



(Above and left): The slightly more expensive (but much better performing) RTL-SDR Blog V3. Unlike the other dongle, this has a re-designed PCB incorporating the direct sampling components.

complete with IR remote control receiver, indicator LED and holes for mounting an RF input connector.

The lower PCB provides the additional components and circuitry for a direct-sampling (Q-branch) LF-HF input range, sharing the new SMA input socket.

I found this unit to work fairly well. Its performance compares favourably with that of the Banggood kit SDR I reviewed in the November 2017 issue.

The measured performance of both can be seen in Figure 4.

This compares the performance of the kit SDR we previously reviewed, to both the new "V.3" RTL.SDR and the Blog V3 described below.

This shows that the performance of the new unit is very close to that of the kit on the LF-HF direct sampling range, while its sensitivity on the VHF-UHF range is significantly worse, especially at the top end.

Like all of the RTL-SDRs we're discussing in these articles, the "V.3" unit is fully compatible with SDR PC applications like SDR#.

It doesn't come with this software, but you can download it for free from the Airspy website (www.airspy.com).

You can also download a "Quick Start Guide" PDF from www.rtl-sdr.com, which explains a lot about installing SDR# and the drivers it needs to communicate with a dongle-based SDR.

The RTL-SDR Blog V3

I also purchased one of the original units that was cloned: the RTL-SDR Blog V3 from rtl-sdr.com

You can buy this from RTL-SDR (either directly or through Amazon) for US$21.95 plus postage, or from their Australian representatives, South Eastern Communications (www.secomms.com.au) for A$35.00 plus $11.60 postage.

I ordered mine from South Eastern Communications.

It comes in a neat little extruded aluminium case like the Banggood "V.3" unit, and it's almost identical in size. But inside, all of the circuitry is on a single, completely redesigned PCB, as shown above.

It has various additions and improvements, including a choke in the USB power line to reduce USB noise and a thermal pad under the PCB to keep the circuitry cooler by conducting heat to the metal case.

There's also a 10dB RF preamplifier in the LF-HF line between the diplexer and the bandpass filter, to improve the sensitivity.

Other features include an additional shunt diode at the input to provide improved ESD protection, and a USB-powered 'bias tee' at the input to allow it to provide phantom power to RF amplifiers and active antennas.

The bias tee is controlled by software, but SDR# and many of the other SDR applications don't allow this to be done directly; it needs to be done using separate batch files.

Before doing any serious testing of this unit, I downloaded and read both its data sheet and User Guide (from the rtl-sdr.com website).

I was glad that I did, because I discovered that its 'bias tee' circuit is enabled by default, and can be damaged by connecting the RF input to a low-resistance antenna or signal generator – unless you disable it.

I also discovered that the bias tee circuit can be disabled permanently by removing SMD inductor L13 (near the SMA input socket).

This also improves the performance on the LF-HF range. So I fired up my soldering iron and carefully removed L13, before reassembling the RTL-SDR Blog V3 and starting my tests.

It soon became apparent that the performance of this unit is significantly better than that of either the RTL.SDR "V.3" or the original RTL-SDR kit. The test results are summarised in figure 4, and if you compare them against the other curves, you'll see that the Blog V3 is well ahead on both ranges.

To summarise, the RTL-SDR Blog V3 is the best performer of the lot. It does cost a few dollars more (especially if you buy it via the local agents), but that's worthwhile for the performance improvement.

COMING NEXT MONTH:

In the second part of this feature, we'll test some of the larger RTL-SDR units with built-in upconverters, which should provide improved LF-HF reception. Stay tuned! *SC*

Useful Links

- www.secomms.com.au (Australian supplier of the RTL-SDR Blog V3)
- www.airspy.com (best current source of the SDR# application)
- https://rtl1090.com (ADS-B application; ADSB# is no longer available)
- www.hdsdr.de (source of the HDSDR application)
- https://zadig.akeo.ie/ (source of Zadig, the Windows generic USB driver installer needed by most SDR software)
- www.rtl-sdr.com (an excellent source of information on RTL-SDR)
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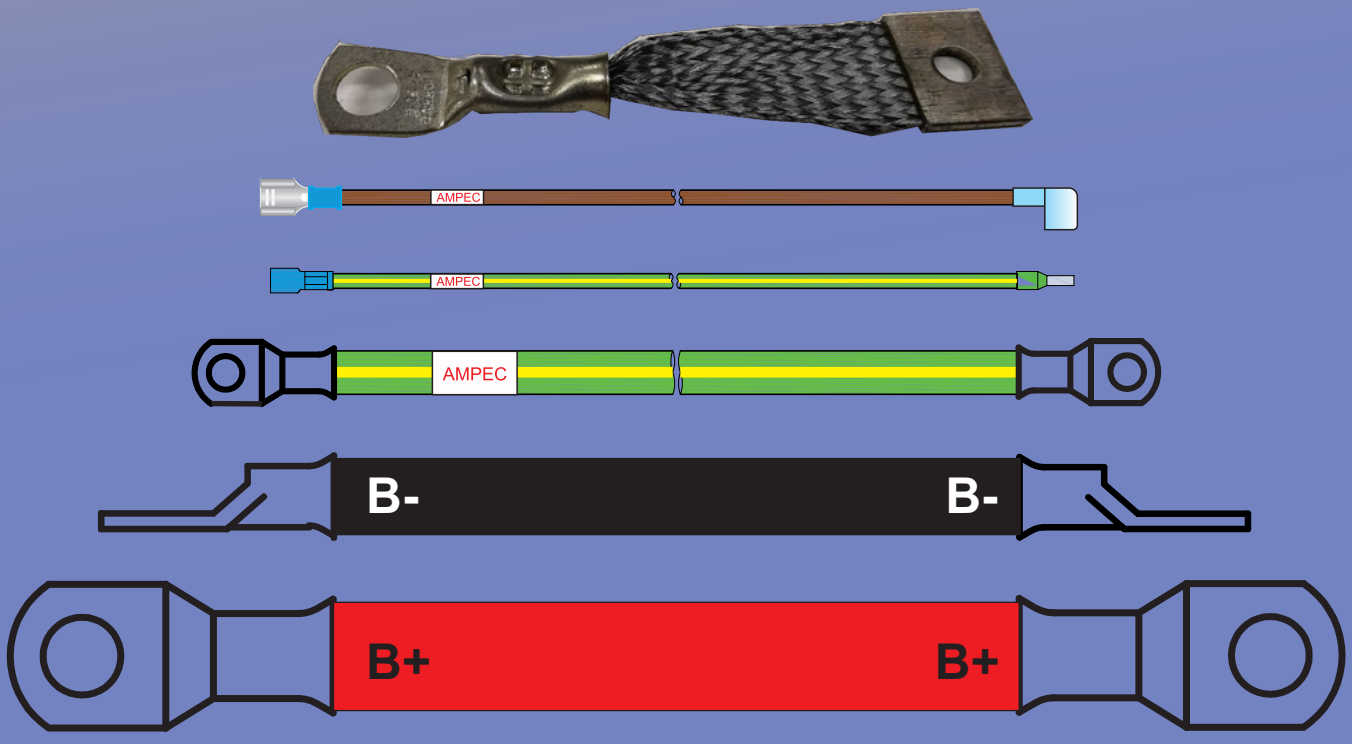

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By
Peter Bennett

A TOUCHSCREEN CAR ALTIMETER

This modified version of Jim Rowe's Touchscreen Altimeter is optimised for use in a car, truck or other land-based vehicle, rather than a glider or ultralight aeroplane. The hardware has been simplified and adapted to be powered from the vehicle, while the software has been updated to make its readings more accurate on a typical driving trip.

This is a modified version of the Touchscreen Altimeter and Weather Station project from December 2017 (siliconchip.com.au/Article/10898), to better suit car usage.

You might be wondering why I want an altimeter in my car. I find it interesting to know how high I am when driving in the mountains, especially when stopping at lookouts (some have their altitude posted, but not all).

Also, engine performance is reduced at altitude, so the information may do more for you than just satisfy your curiosity.

The power output of naturally aspirated petrol engines drops by about 3-4% per 300m (1000ft); turbocharged engines are less affected, but can still lose some power due to the thinner air at higher altitudes, depending on their particular design.

In a motor vehicle, the Altimeter can be powered from the vehicle's accessory socket, so there is no need for the internal battery used in the original design. This means that we can fit all the hardware in a single UB3 Jiffy box, with an exhaust fan to remove the heat generated by the display, avoiding the need the mount the sensors in a separate box.

In this design, power is supplied via a USB cable. Many modern cars have USB charging sockets. If yours doesn't, you can use a USB charger plugged into the accessory socket.

You can buy low-cost pre-built altimeters but they are not very accurate. That's because they typically convert the air pressure reading to altitude with reference to "Mean Sea Level" (MSL), a pressure of 1013.25hPa. But sea level pressure can vary (in extreme weather) from 870hPa to 1084.8hPa, an error range of 1770m/5800ft.

Of course, we seldom see the extremes, but you can see that basing an altitude reading on MSL will often lead to significant altitude errors.

To solve this, I have modified the Altimeter software so that you can set the local altitude, such as the altitude of your driveway or a lookout (it's usually given), to give a very accurate reference pressure, your local QNH.

The original Altimeter software stored the QNH setting when you turned it off, and loaded it again at startup.

If you drive to a pretty spot for a picnic and shut the Altimeter down, it will restore with the same QNH

Here's the altimeter built into the standard (DIN) dash cutout in my car. Being such a large screen, it's very easy to read. As the screen says, you can change both the mode and units (eg, feet above sea level, as seen here [which is used in aviation] to metres above sea level, which we're all familiar with). Incidentally, QNH means the atmospheric pressure adjusted to mean sea level. It is neither constant nor the same for various locations – you can get the QNH from weather services.

and preferences when you power up to depart.

But if you stayed overnight, the QNH will probably be significantly different when you set off in the morning, leading to errors that accumulate with each stop.

To solve this, the Vehicle Altimeter software records the ground altitude when you power down and uses this value to compute the new QNH on power-up.

The assumption is that the vehicle does not change altitude while you are not driving it (hopefully, a safe assumption!). So the unit should remain accurate for a whole trip, as long as you set its altitude correctly at the start.

This saves you from having to frequently check the current QNH at your location (via the internet, for example) and update the unit to maintain accuracy.

The Car Altimeter is sized to fit into a typical car console pocket (eg, it fits nicely in the console of a Mazda 6). The pocket has an accessories outlet which is hidden, along with the USB adaptor, to the left of the Altimeter.

Circuit changes

The modified Altimeter circuit is shown in Fig.1.

In addition to the Micromite LCD BackPack, DHT22 temperature/humidity sensor and BMP180 temperature/pressure sensor retained from the previous design, the following elements have been added: a fan with PWM speed control, a small Li-ion battery and a relay driven by a Mosfet plus several diodes.

The PWM control circuity for the cooling fan is provided to keep its noise to a minimum, as small cooling fans are notoriously noisy. This is based on a standard NPN transistor, Q1, driven from Micromite pin 24 via a 2.7kΩ resistor. Schottky diode D5 prevents back-EMF spikes from the fan damaging Q1.

The software uses a PWM frequency of 20Hz with a 50% duty cycle. This gives adequate airflow with minimal noise.

So that the unit can save the altitude at power down, we need to monitor the 5V supply and detect when it starts to drop. Since it drops too fast to give the software enough time to save its settings, rechargeable lithium-ion button cell BAT1 powers the circuit while the 5V rail collapses.

When we have finished storing the data, we switch off the battery supply.

There is another benefit of this battery. The effect of the starter motor on the electrical system of a vehicle can be severe, and the 5V supply can fluctuate enough to upset the Altimeter. By diode isolating the 5V rail from the USB input, and using the lithium-ion battery to provide a stable 3.3V supply, we get a reliable boot-up.

Jumper JP1 is used as a connector to access the 5V supply from the USB socket and to feed 5V back into the BackPack, which flows between these

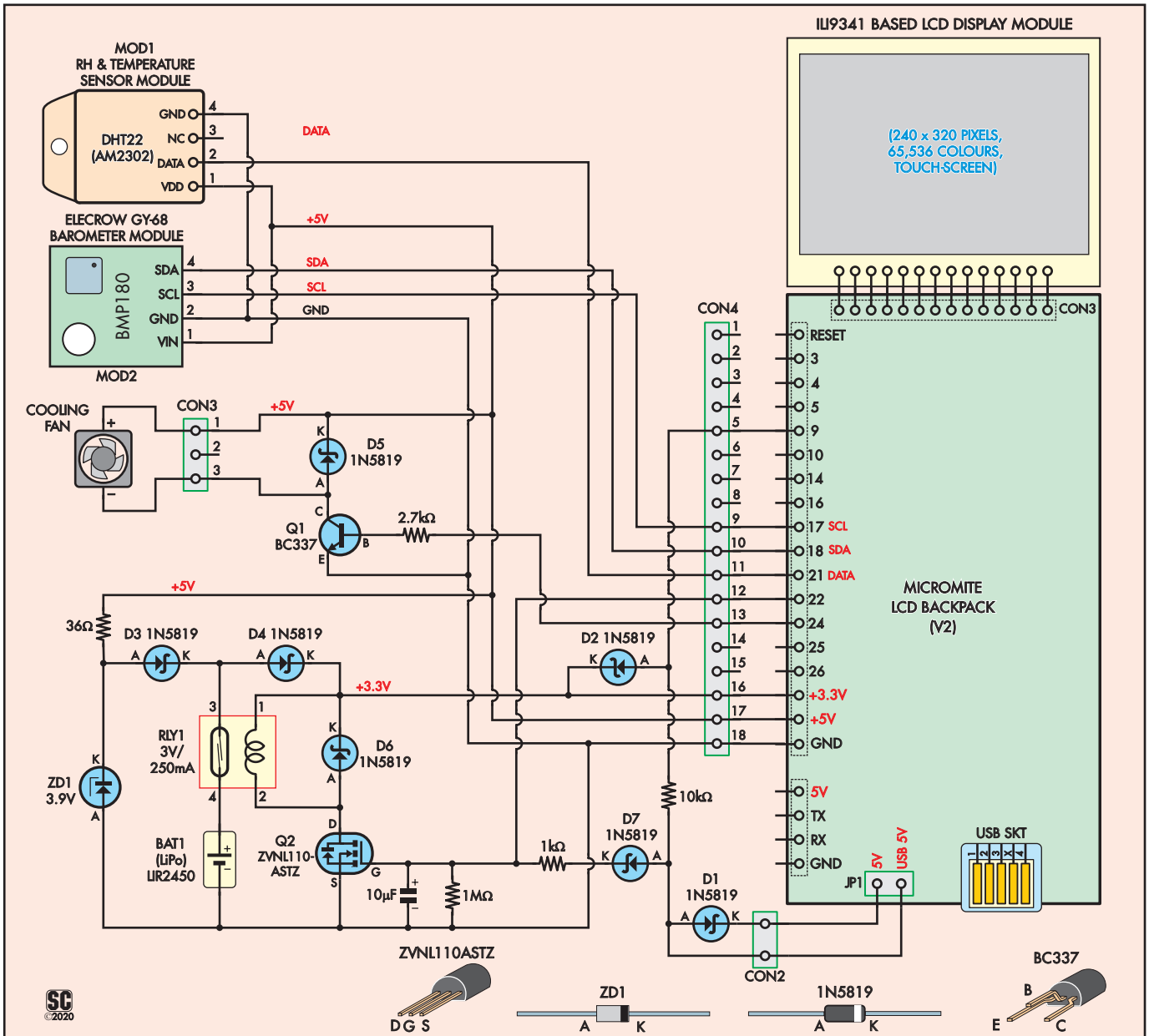


Fig.1: the Car Altimeter circuit is based on that of the Touchscreen Altimeter for Ultralights, but it has been optimised for use in land-based vehicles. This includes the addition of a small PWM-controlled fan to ensure the sensors see fresh air, and a backup battery (BAT1) switched by RLY1 to provide power for a brief time after switch-off, so that the current altitude can be saved into flash memory.

pins via schottky diode D1. The USB +5V also goes to the gate of Mosfet Q1 via another schottky diode (D7) and a 1kΩ resistor. This ensures that Q2 switches on as soon as USB power is available, and it powers the coil of relay RLY1.

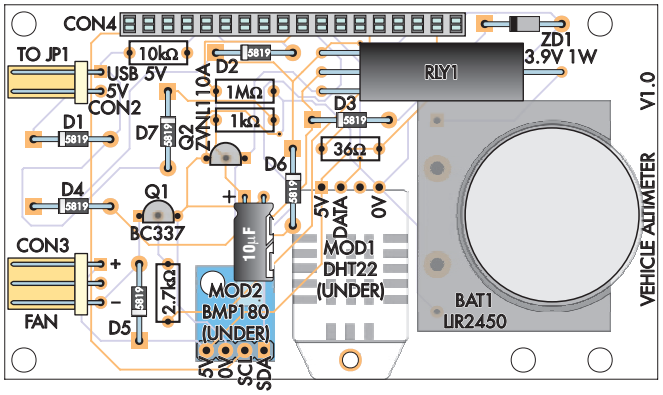
When the 3.3V rail is derived from battery BAT1, the 5V rail sits at 3.3V; it is back-fed through the 3.3V regulator on the BackPack board, from its output to its input via an internal protection diode. D1 prevents this 3.3V from being backfed into the 5V USB source.

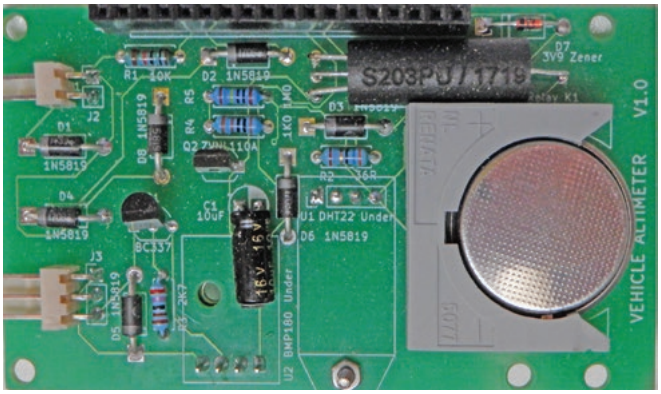
RLY1 connects BAT1 into the circuit when Mosfet Q2 is on. BAT1 is charged from the 5V rail via a 36Ω current-limiting resistor and schottky diode D3. Zener diode ZD1 limits the voltage applied to the battery to a safe level for charging (around 3.6V, taking into account the forward voltage of D3).

BAT1, in turn, powers the +3.3V rail of the BackPack via schottky diode D4. The voltage drop across D4 reduces the 3.6V from the battery to the 3.3V needed. This rail mainly runs the PIC32 micro on the BackPack, which has a recommended maximum of 3.6V and an Absolute Maximum rating of 4.0V.

Micromite pin 9 is used to sense the 5V USB voltage via a 10kΩ resistor, to determine when the external 5V supply switches off, and Micromite pin 22 is pulled low to forcibly bring the gate of Q2 low, switching RLY1 off and powering down the circuit.

One thing not shown on the circuit is that I added a front panel LCD backlight dimming switch to the BackPack. This connects across the BackPack's onboard brightness adjustment trimpot (VR1), shorting it out when the switch is closed and thus selecting between two different





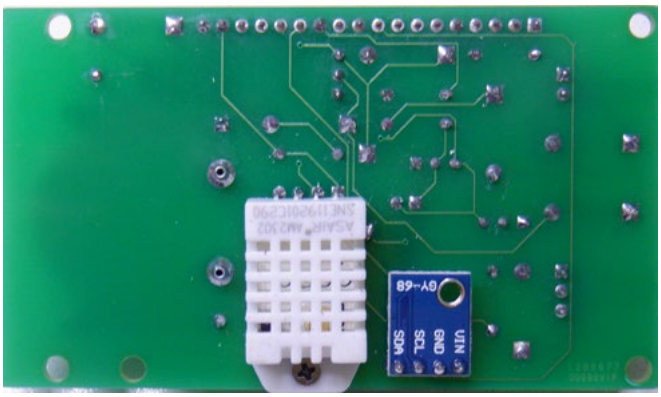


Fig.2: to make assembly easy, all the components which are not part of the Micromite LCD BackPack mount on this similarly-sized PCB, with matching front and back photos at right. Only the two sensors are mounted on the back – everything else is mounted on the front of the PCB, including the cylindrical SPST relay (black component top right of upper pic at right) and the rechargeable button cell holder.

brightness levels: that set by VR1, and full brightness.

This is important so that you can switch the backlight to low brightness at night, to avoid ruining your night vision.

Software changes

The software has been changed in a few places, and some of the changes have been described above. Some improvements have also been made to the user interface.

The weather station and altimeter screens are similar to the original. They show altitude above MSL until the QNH or exact altitude has been entered. After that, they show altitude above QNH (Screen 1 & Screen 2).

The Change Mode screen has new selections that differentiate between entry of QNH and current altitude (Screen 3). The current QNH value is also shown while you enter either current altitude or QNH (Screen 4).

If you want to change the fan PWM frequency or duty cycle, search the BASIC code for the line starting with PWM and change the values of 20 (Hz) or 50 (percent duty cycle) to suit.

Power supply

This Vehicle Altimeter draws about 90mA at 5V. It can be powered from a low-cost USB power bank (such as Jaycar Cat MB3792), providing run times in excess of 24 hours between charges, making this version practical for use outside of a motor vehicle.

Loss of USB power is detected by pin 9 of the Micromite, with a 10kΩ resistor and diode D2 clamping this

Using Weatherzone to get QNH

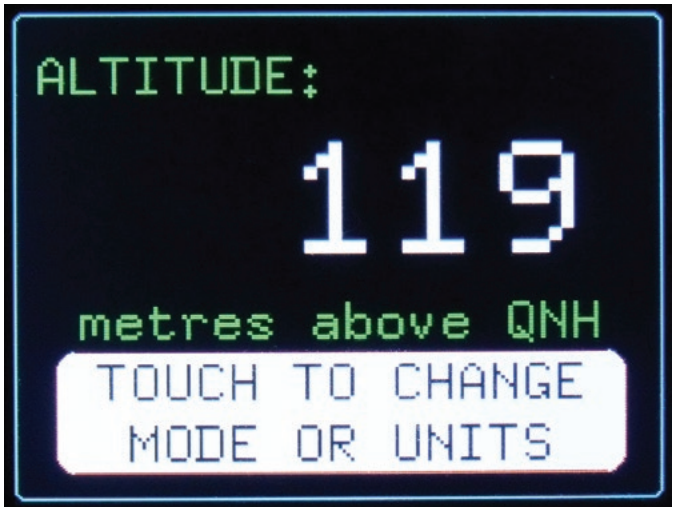
Weatherzone (weatherzone.com.au) is a free mobile app for viewing weather forecasts and related information. It also provides a simple method for getting QNH.

In this example, the screengrab on the left shows the observations at Terrey Hills; there is no QNH observation, so the Pressure field is blank.

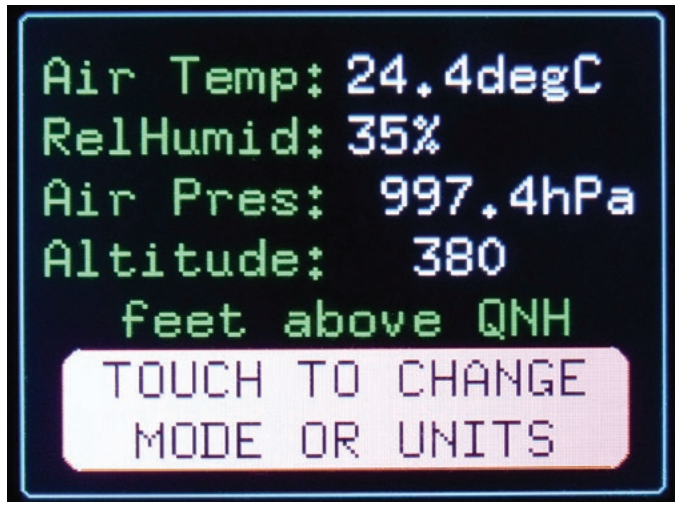
Tapping on the screen takes you to the nearest location with data, which is Sydney. The second screen grab shows that this indicates the current QNH value.

If you want higher accuracy, use the Weather Observations screen for your area from the Bureau of Meteorology. (www.bom.gov.au).

The BOM gives QNH to 0.1hPa resolution.



Screen 1: the main screen after setting QNH. This shows your altitude above QNH (effectively sea level) in metres or feet.



Screen 2: the extended information screen after setting QNH, showing the altitude in feet along with air temperature, relative humidity and atmospheric pressure readings.

signal to the 3V3 rail, as Micromite pin 9 is not 5V-tolerant. Power to the Micromite is held on for a short time after the loss of USB power due to the 10µF capacitor at the gate of Q2, which slowly discharges through its parallel 1MΩ resistor. During this time, the Micromite runs from BAT1.

The change in level at Micromite pin 9 triggers a software interrupt that causes the Micromite to store the current altitude data. Micromite pin 22 is then switched low, turning off Q2 and releasing the relay, shutting everything down. Diode D6 suppresses any voltage spike across the relay coil.

In practice, the Micromite runs for about 200ms after a loss of 5V power. This gives the BackPack time to send the message "Saved" to a terminal attached to the USB cable before the 3.3V supply goes away. You will notice the display dimming briefly as the display backlight runs from 3.3V rather than 5V before it switches off.

Note that the selection of Mosfet Q2 is not critical. Any N-channel enhancement mode Mosfet with a continuous drain current of at least 300mA and a maximum gate-threshold voltage up to 2.0V (typically those designed to be driven from a 3.3V logic supply) should work as well as the ZVNL110A.

However, we have not tested any substitutes.

Construction

I have designed a double-sided PCB which holds all the components of the Vehicle Altimeter, as shown in Fig.2 and the accompanying photos.

The two sensors (BMP180 & DHT22) mount on the back. This keeps the sensors away from the heat-producing components, in a dedicated cool airstream between an inlet and outlet in the case. This board plugs directly into the LCD BackPack.

Start by begging, borrowing or building the BackPack. We suggest you build V2, although the original will work. We don't recommend using V3 as the Altimeter software is not designed to accommodate the larger screen, and the inside depth of the V3 box is reduced because of its recessed front panel.

The BackPack V2 construction is fully described in SILICON CHIP, May 2017, starting on page 84 (**siliconchip.com.au/Article/10652**).

But given its relative simplicity and the fact that a kit is available and the PCB silkscreen shows where the components go, you don't really need to read that article. Simply fit the components where shown on the PCB, and it should work.

Once you've built and tested the BackPack, wire up a toggle switch across trimpot VR1 so that when the switch is closed, VR1 is shorted out and the LCD screen operates at maximum brightness. When it is off, the brightness is set by VR1, which you should adjust to a comfortable level for nighttime viewing.

Note that there are two otherwise identical versions of the 2.8-inch 320x240 LCD touchscreen, one of which uses backlight current control and one which uses voltage control.

If the 100Ω trimpot supplied for VR1 does not adjust the backlight brightness properly, replace it with a 100kΩ potentiometer and wire its unconnected pin to ground. That should do the trick.

Now assemble the interface board by mounting the resistors and diodes on the front side.

Next add the battery clip, connectors CON2-CON4 and relay RLY1. RLY1 is in a bit of an odd cylindrical package, with three wires at one end and one at the other. Ensure that its type number is facing up and solder it as shown in Fig.2 and the photos.

On the underside, carefully bend the pins of the DHT22 against its body so they pass through the pads.

Attach the sensor with a 2mm screw and solder the terminals, then prepare the BMP180 for mounting by soldering the supplied 4-pin header to its terminals. Secure the assembly to the PCB and solder the header to the PCB respective pads. Check that "SDA" connects to the square pad.

The single capacitor is an electrolytic type which is fitted bent over on its side. Make sure the longer (positive) lead goes to the square pad, marked

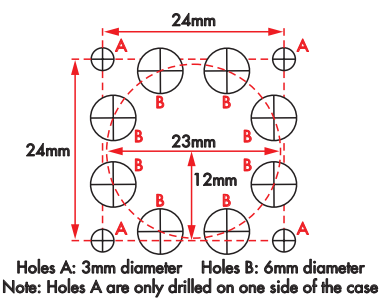
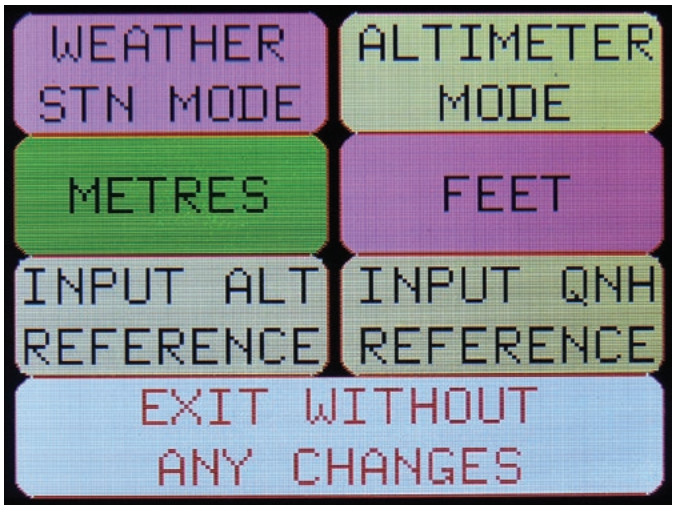


Fig.3: use this diagram as a guide or template to drill the eight airflow holes at both ends of the case, plus the four mounting holes for the fan at the right-hand end.



Screen 3: the settings screen has two buttons at the bottom for calibration; one for entering the currently known QNH value, and one for entering your current altitude in feet.

Screen 4: the current value of QNH is shown as you are typing the new one, to remind you which value you are updating.

+. Secure the body of the capacitor to the board with a dab of silicone adhesive or a piece of double-sided foam mounting tape. Add Mosfet Q2 and BC337 transistor Q1 where shown, and the board is complete.

Case preparation

Next, prepare the UB3 Jiffy box. The cooling fan mounts on the right-hand end, looking at it from the front (lid), as far towards the back as practical.

Drill four 3mm mounting holes, each at the corner of a 24x24mm square (or simply mark the positions using the fan, then drill). You then need to drill some holes inside its footprint to allow air through. I suggest eight 6mm holes arranged equally around a 23mm diameter circle. You can use Fig.3 as a template to mark these holes before drilling.

Drill the same eight air inlet holes on the left-hand end of the case, opposite the fan, but without the fan mounting holes.

Next, locate a convenient point on the back of the box for the USB cable to exit. Drill an 11.5mm diameter hole to take a cord grip clamp. We located it 20mm from the fan end (RH), 10mm from the top. This gives enough length to withdraw the electronics from the box.

Drill a hole in the front panel to mount the dimmer switch, ensuring the switch clears the fan and BackPack connectors.

Cut the cooling fan leads to about 150mm and attach the 3-pin female socket to match CON3 on the interface board. Then make up the 2-pin cable linking CON2 on the interface board to LK1 on the backpack.

To connect to LK1, cut a two-contact section from the leftover remnant of the strip used to make CON4, fold the pins against the body, solder the wires to the pins and heat shrink the wires to the body. This keeps the connector short enough to fit between the BackPack LK1 and the display.

Carefully check the connections. If you swap the wires, diode D1 on the interface board will isolate everything from the 5V input.

The USB cable is a tight fit against the end of the box. We carefully removed some of the plastic reinforcement at the mini connector, and applied gentle heat to persuade the cable to lie in our preferred direction.

The USB mini connector can be inserted through the exit hole in the back of the box and the cable secured with the cord grip clamp. Insert the LIR2450

Parts list – Car/Truck Altimeter

1 assembled Micromite LCD BackPack (V1 or V2) [Silicon Chip Cat SC4024 or SC4237]
1 DHT22 temperature/humidity sensor (MOD1)
1 GY-68 BMP-180 temperature/pressure sensor module (MOD2)
1 double-sided PCB, coded 05105201, 86.5 x 49.5mm
1 black or grey UB3 Jiffy box [Jaycar HB6013/HB6023]
1 panel-mount SPST/SPDT toggle switch [eg, Jaycar ST0335]
1 thin 30mm 12V DC cooling fan [Jaycar YX2501]
1 3V DC coil, 250mA SPST reed relay (RLY1) [RS Cat 124-5129]
1 PCB-mount 2450 coin cell holder (BAT1) [element14 Cat 1216361]
1 LIR2450 Li-ion rechargeable cell (BAT1) [element14 Cat 2009025]
1 2-pin right-angle polarised header and matching plug (CON2)
1 3-pin right-angle polarised header and matching plug (CON3)
1 18-pin header socket (CON4)
1 50cm+ USB cable [eg, Jaycar WC7709]
1 6.2-7.4mm cordgrip clamp [Jaycar HP0718]
4 12mm-long M3 tapped Nylon spacers
4 M3 x 15mm machine screws

Semiconductors
1 BC337 NPN transistor, TO-92 (Q1)
1 ZVNL110ASTZ N-channel Mosfet or similar, TO-92 (Q2) [RS Cat 823-1833]
1 3.9V 1W zener diode (ZD1) [eg, 1N4730]
7 1N5819 1A shottky diodes (D1-D6,D8)

Capacitors
1 10µF 16V electrolytic

Resistors (all 1/4W 1% metal film)
1 1MΩ 1 10kΩ 1 2.7kΩ 1 1kΩ 1 36Ω

battery into its clip, mount the interface board on the BackPack with 12mm untapped spacers and 20mm M3 screws. Construction is now complete.

Testing

Load the revised Altimeter software named "*Altimeter with power fail 1_0.bas*" (available for download from the SILICON CHIP website) into the Micromite and run it. The first time it is run, the display should initialise with the weather station screen using MSL as the reference.

Connect the Altimeter to a terminal such as Teraterm or MMEdit. The LED on the BackPack should flash twice per second as the Micromite sends the message "pass" to the terminal. If the Altimeter fails to start, check the connection from CON2 to LK1. The cooling fan should run if the software has initialised.

Check that the battery is charging. It should be approaching 3.6V. The voltage drop across the 36Ω resistor should be about 0.9-1.1V when the battery is charged. You can probe this on the reverse side of the board.

Check the touchscreen selections for correct function. To find the QNH to enter, the best method is to use an app such as Weatherzone (see panel). On Weatherzone's current forecast screen for your location is a field labelled "Pressure". If the value is blank, tap the screen to step to the nearest QNH observation.

When you make a change such as entering QNH or Alt reference (current known altitude), you may notice the altitude reading converging on the final value over five seconds.

This is because this software version averages the readings to eliminate short term fluctuations and improve the accuracy of the saved altitude at power down.

With a terminal connected and monitoring the USB signal, the terminal should show "pass" once per second. Disconnect the cable from CON2. The terminal should display the message "saved", indicating that the current altitude has been saved.

Assemble the front panel to the box. You may have to source longer self-tapping screws than those provided, or you can tap the mounting bosses and use machine screws.

The Altimeter should now be ready for use.

Precision, accuracy and errors

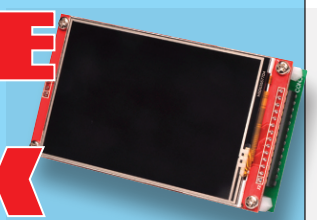
Remember that a pressure altimeter is not an instrument of survey accuracy. Even if it can display altitude to a precision of one foot, it is likely to be displaying the wrong altitude very precisely because it is subject to several variables.

One such variable is QNH drift. The Bureau of Meteorology is continually amending QNH, and pilots must continually correct their altimeters. Also, the QNH derived from Weatherzone is truncated to the unit of hPa. Straight away, you have a possible error of ±30ft/10m.

Another error derives from temperature differential. If you park in the sun and turn off the engine, the current altitude will be saved. However, when you return and restart the engine, the car interior temperature could be 20°C higher than ambient. The Altimeter will use this temperature to calculate the new QNH. This error can be up to 6m/20ft for a 20°C difference.

These errors would be unacceptable for night instrument landings, but are not a big deal for either road travel or recreational aviation. Don't stress. Re-enter the QNH and go and enjoy! SC

AUSTRALIA'S OWN
MICROMITE TOUCHSCREEN BACKPACK



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- Tariff Super Clock (Jul18 – siliconchip.com.au/Article11137)
- Altimeter & Weather Station (Dec17 – siliconchip.com.au/Article/10898)
- Radio IF Alignment (Sep17– siliconchip.com.au/Article/10799)
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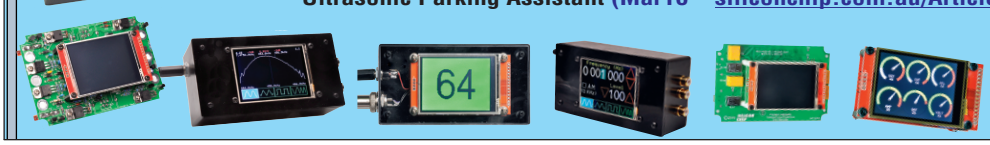

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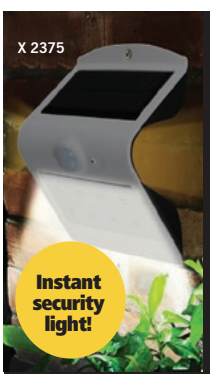

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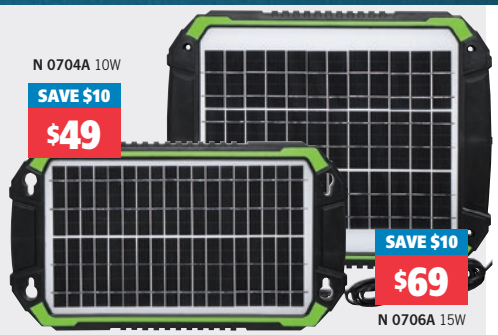

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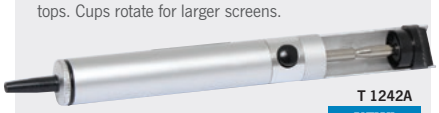

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B 0090

CIRCUIT NOTEBOOK

Interesting circuit ideas which we have checked but not built and tested. Contributions will be paid for at standard rates. All submissions should include full name, address & phone number.

3-output power supply using plugpacks

This circuit shows how you can get a ±15V 1A split supply, plus a separate 5V, 200mA logic supply, just using a pair of plugpacks or 'brick' type supplies, like those used to power and charge laptops. These are readily available, relatively inexpensive, small and light. The resulting device will likely be smaller and lighter than a transformer-based solution.

Before stacking switchmode supplies as shown here, if the supply has an Earth pin, use a DMM set to measure ohms to ensure that there is no connection (when unplugged) between the Earth pin and either output. If there is, they are not suitable for stacking.

Most such supplies have floating outputs, so the positive output of the lower supply is connected to the negative output of the upper supply. This junction forms the ground connection, with the upper V_{OUT+} being nominally +19V and the lower V_{OUT-} being nominally -19V.

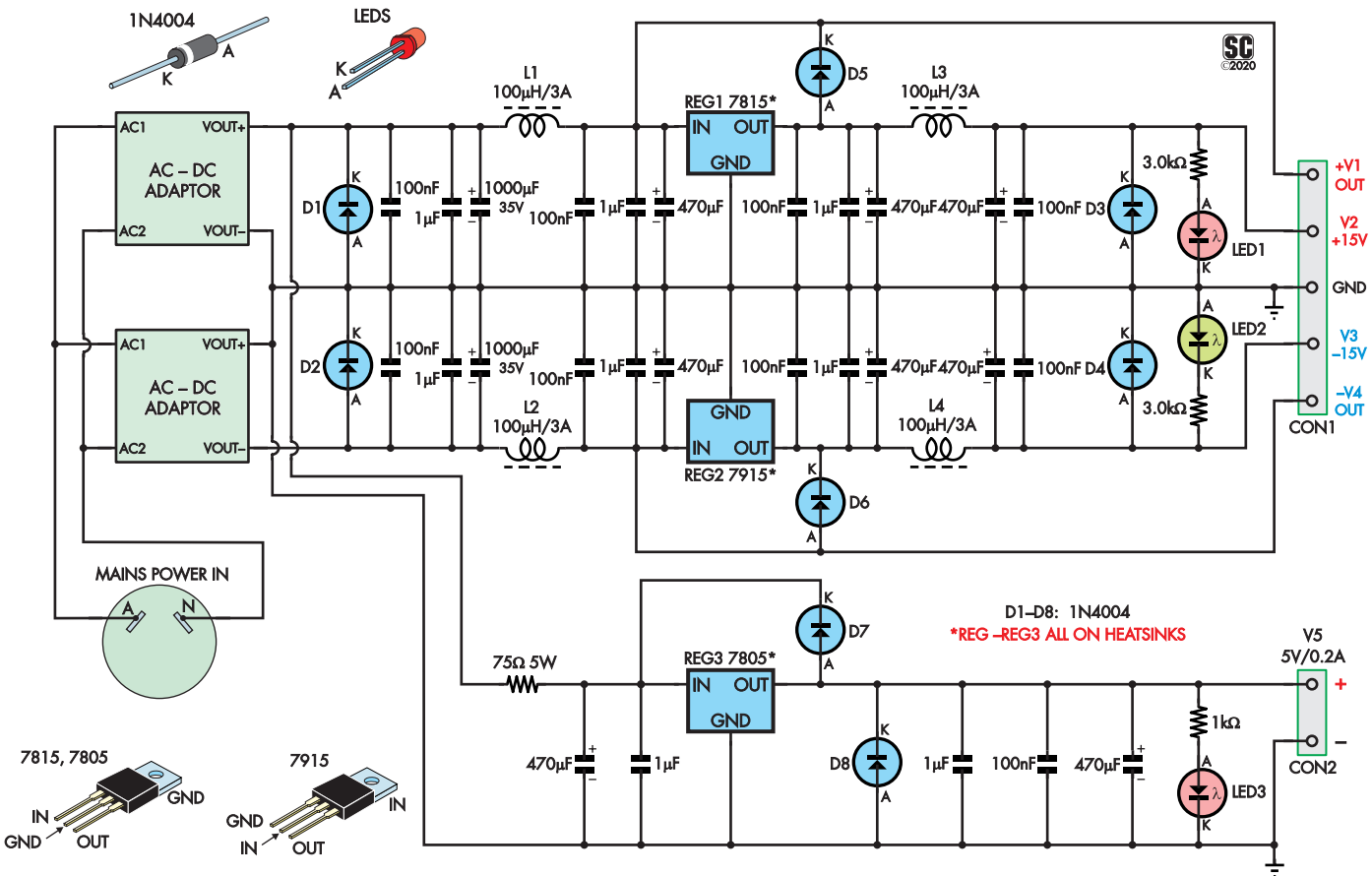
These two supply rails are then fed through pi filters comprising 100µH 3A inductors with sets of three capacitors on either side. Multiple capacitor values are paralleled to provide good performance over a wide range of frequencies. This helps eliminate most of the switchmode hash which may be present in the outputs of such supplies, and the following linear regulators do the rest.

The outputs of REG1 & REG2 pass through another pair of pi filters, so that the ±15V rails are super clean; however, you could probably omit these with no ill effects (they also reduce regulation). The regulated and unregulated filtered supplies are fed to CON1 for outside use. LED1 and LED2 indicate that the rails are present.

Diodes D1 & D2 protect against reversed supply polarity, as the switchmode supplies will go into current limiting or shut down due to the high current that would flow if that happens. Diodes D3 & D4 prevent the positive outputs going negative and the negative output going positive if the two mains supplies do not come up simultaneously, while D5 and D6 protect REG1 and REG2 should the V1 or V4 rails be shorted to ground.

The output of the upper mains supply is separately filtered by a 75Ω/470µF RC filter and fed to REG3 to generate the 5V logic supply at CON2. It is this 75Ω 5W resistor which limits the 5V output to 200mA. Diodes D7 and D8 protect REG3 against output short circuits to higher voltages and ground, while LED3 indicates when this rail is powered.

Petre Petrov,
Sofia, Bulgaria. ($70)



Variable speed discrete reversing LED chaser

I was inspired to design this circuit by the "LED Headband" project which appeared in *Electronics Australia*, January 1983. This was a simple four-stage LED chaser driving 12 LEDs in three groups. The LEDs were arranged around a headband to produce the effect of lights rotating around the wearer's head.

I thought the effect could be taken a few steps further, by varying the speed at which the LEDs chase – starting from stationary and speeding up to peak speed then slowing back to a stop. I also wanted to make the LEDs reverse after stopping, and chase back the other way. The circuit shown here is the result of my endeavours.

The circuitry around CD4069 hex inverter IC1 is adapted from the Technilab 301 Function Generator described in the March 1988 issue of SILICON CHIP. IC1b and IC1c are arranged as a Schmitt trigger with the output feeding IC1a, configured to operate in linear mode as an inverting integrator.

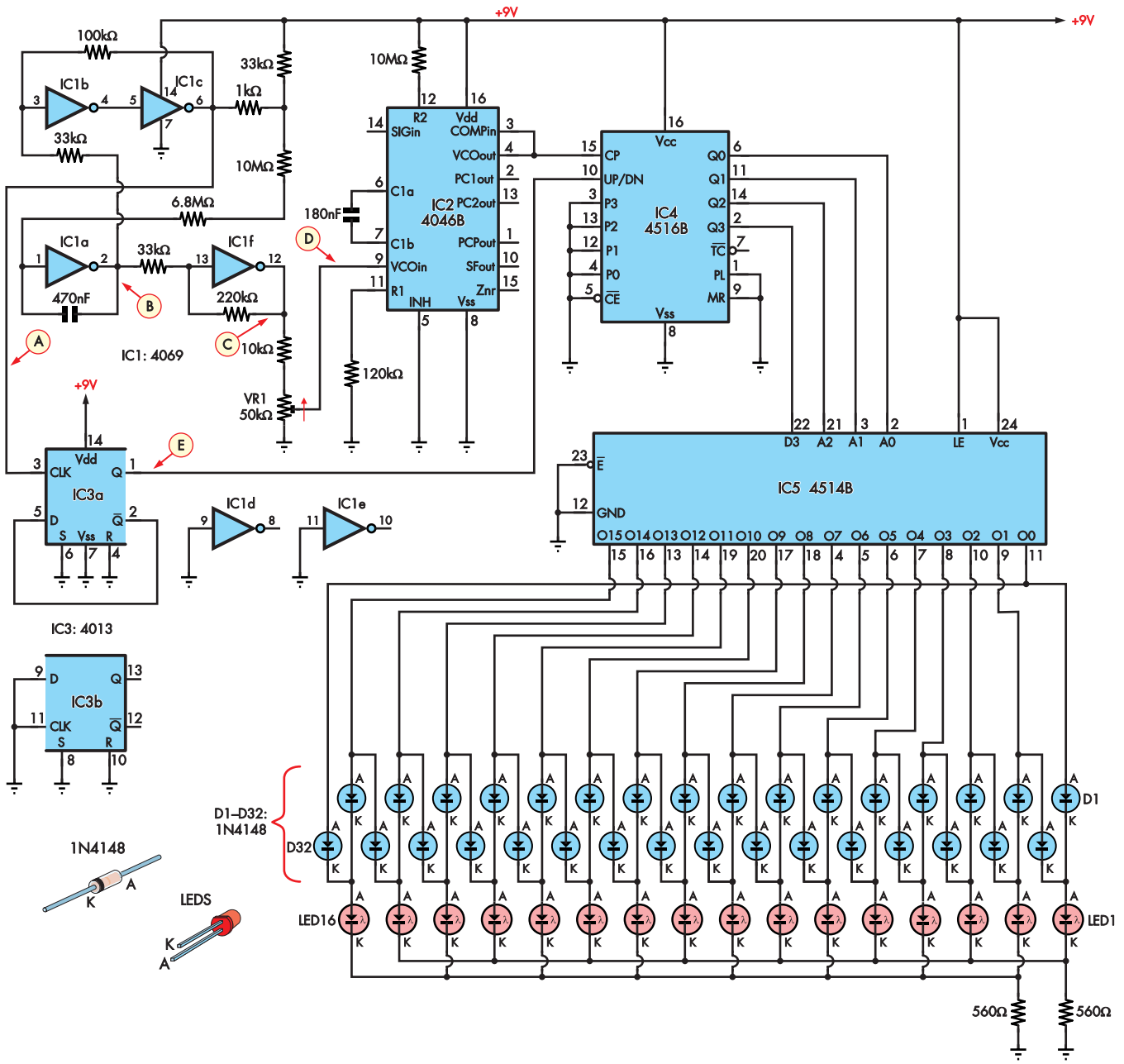
The integrator output ramps up if the Schmitt trigger output is low, and ramps down if it is high. The ramp output is fed back to the input of the Schmitt trigger, to toggle it when its switching threshold is reached.

The result is that IC1a, IC1b and IC1c together form an oscillator with a frequency set by the values of resistance and capacitance around the integrator, with a square wave output at the pin 6 output of IC1c (waveform "A") and a triangle wave output at output pin 2 of IC1a (waveform "B").

With the R and C values shown (10MΩ, 6.8MΩ and 470nF), its oscillation frequency is approximately 0.5Hz.

The triangle wave is then processed by IC1f, operating in linear mode as a soft limiter, to produce an approximate sinewave at its pin 12 output (waveform "C").

IC2 is a CD4046 phase-locked loop (PLL) IC, but here only the voltage-controlled oscillator (VCO) part is used. The frequency of the VCO is set by the 120kΩ resistor from pin 11 to ground,



the 180nF capacitor between pins 6 and 7 and by the control voltage fed to it at pin 9, ie, the ~0.5Hz sinewave.

VR1 sets the level of the sinewave applied to the VCO (waveform "D") and hence the peak frequency of the VCO. So, the VCO frequency will vary from 0Hz up to a maximum at the upper peak of the sinewave, then die back to zero over about two seconds.

IC3a is a CD4013 D-type flip-flop which simply divides the square wave output frequency from the oscillator by two (waveform "E"), to control the direction of counting in IC4 (a CD4516 binary up/down counter). Its preset count function is not used in this application.

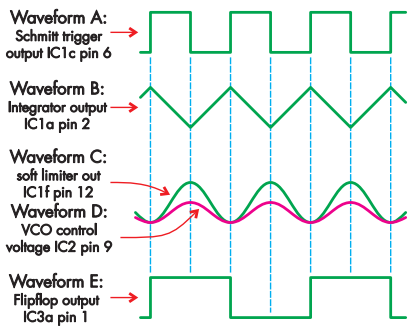
It counts the varying frequency pulse train output of VCOout, and delivers the count at its four binary outputs Q0-Q3. Whether it counts up or down is determined by the control applied to its pin 10, which comes from IC3a. If the control applied to pin 10 is high, it counts up; if low, it counts down.

IC4 therefore counts up for one IC1 oscillator period, then down for the next, repeating forever.

IC5 (CD4514) is a 4-to-16 decoder with active low outputs. It decodes the Q0-Q3 binary outputs from IC4, taking the appropriate output high, thus turning on the corresponding LED(s). The overall effect then is that the LEDs at the IC5 outputs are turned on sequentially in one direction at increasing then decreasing speed, then repeating in the opposite direction.

Diodes D1 to D32 enhance the effect of "rolling" rather than "stepping" chase motion by OR-ing adjacent IC5 outputs so that not only is the primary selected LED on, but also is its immediate predecessor.

Bob Martindale,
Mill Park, Vic. ($80)



SC ©2019 **LED CHASER WAVEFORM RELATIONSHIPS**

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Proximity warning for the blind

This Raspberry Pi-based device informs a blind person about the distance to nearby objects using sound and vibration.

The idea is to mount it on a cane, as shown in the accompanying diagram. It automatically measures the distance to the nearest object in front of the cane and reads it out to the user. It also vibrates the handle if that distance is below one of two programmed thresholds.

There isn't much to this circuit. Besides the Raspberry Pi, it uses the ubiquitous HC-SR04 ultrasonic distance measurement module, a DS18B20 1-wire digital temperature sensor, MCP23008 I/O expander module, alphanumeric LCD module (admittedly not very useful to the blind person!), two 5V DC coil relays with driving transistors and back-EMF quenching diodes, plus a small speaker or pair of earphones.

The relays drive two vibration units which are basically unbalanced motors which produce noticeable shaking when they are powered from 5V. These are often used in mobile phones and can be purchased cheaply online.

The LCD screen and I/O expander could be left off and the device will still work; they are primarily debugging aids. The I/O expander is controlled from the Raspberry Pi over an I^{2}C bus and is used so that the Pi's 3.3V outputs can drive the LCD which runs from 5V.

The I^{2}C address for IC1 is set to 0x20 by tying its pins A0-A2 to ground; if you change these connections, you also need to modify the contents of the file named lcd23008.py to match (more on the software later).

Similarly to the July 2019 project on Speech Synthesis with a Raspberry Pi Zero (siliconchip.com.au/Article/11703), this project uses the "espeak" software for speech synthesis. This allows it to convert measured distances into spoken words for the blind person to hear.

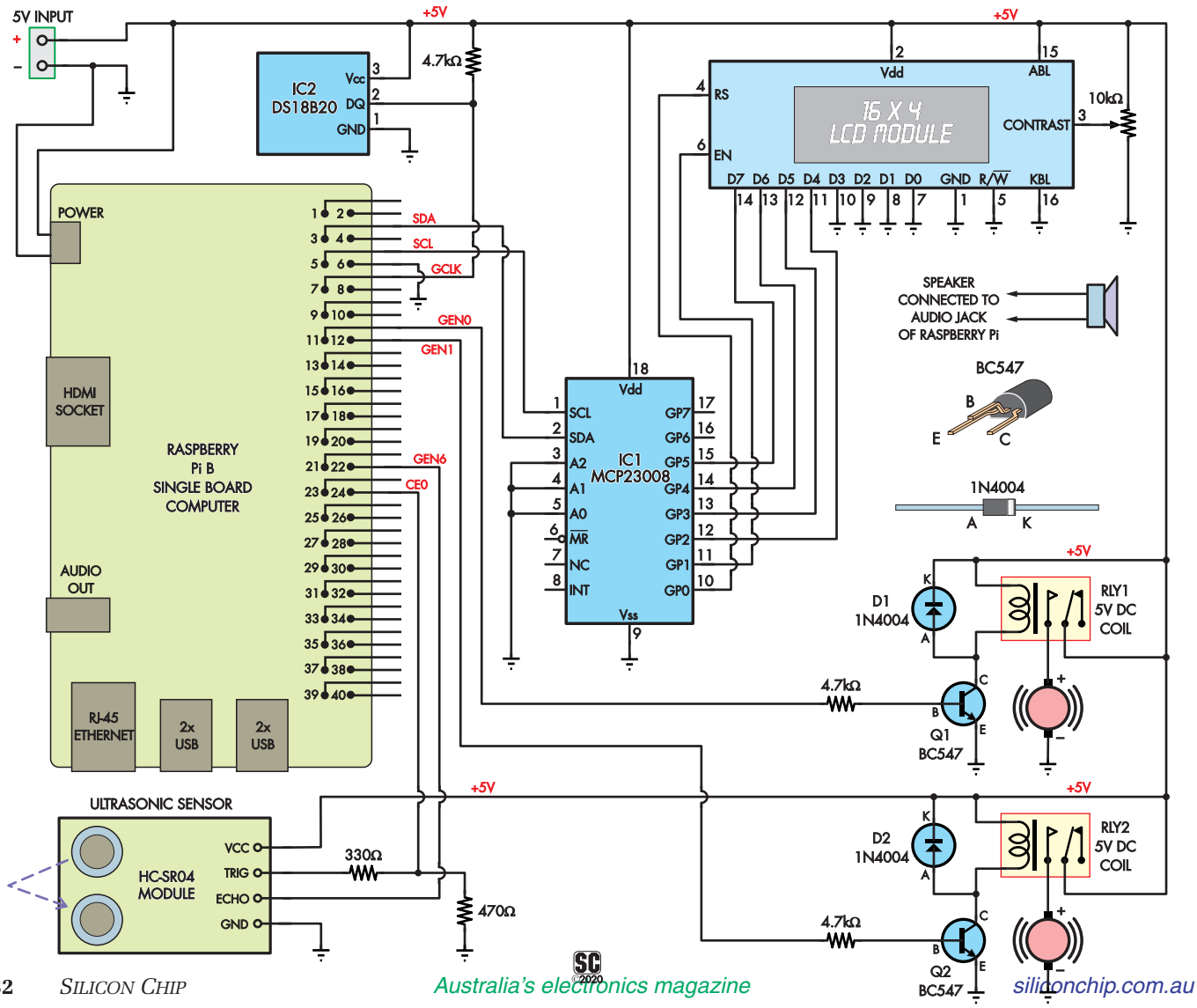
To install espeak on a freshly installed Raspberry Pi, use the following sequence of commands:

```
sudo apt-get update
sudo apt-get upgrade
sudo apt-get install alsa-utils
  mplayer espeak espeak-gui
sudo 'echo snd_bcm2835>>/etc/
  modules'
sudo reboot
```

Once the Pi has rebooted, connect a speaker or earphones/headphones to its audio output and then use the following command to check that espeak is working:

```
espeak "Testing: 1, 2, 3"
```

The other software that we need is "rpi-gpio". You can download and



install the latest version from: https://pypi.org/project/RPi.GPIO/

In operation, the Raspberry Pi software continually checks the output of the ultrasonic distance sensor. If it changes by more than about 2cm, it uses espeak to read out the new distance measurement. The sensor responds to objects in an arc approximately 15° either side of its primary axis, up to around 2m away.

The software is written in Python and consists of four .py files, all of which are contained within a ZIP package which can be downloaded from siliconchip.com.au/Shop/6

Copy this onto your Raspberry Pi "/home/pi" folder and unzip it.

If you are using a speaker or earphones with built-in volume control, the default audio volume level should be suitable.

Otherwise, open up the ultra3.py file in a text editor to change the volume setting to something more reasonable. Look for the line with the value "-a220" and change the number. "-a200" is full volume; increasing the value after the "a" lowers the volume. You can then test it by running the following command:

```
sudo python /home/pi/ultra3.py
```

It takes a little time to initialise the first time you run it. You will hear a greeting message, and then the program goes into a loop, measuring the distance and reporting it if it changes.

If the measurement is over 2m (essentially, upon first detection), then pin 11 (GPIO 17) goes high, energising RLY1 and causing one vibration motor to spin. If the measurement is below 1m then pin 12 (GPIO 18) goes high, energising RLY2 and causing the other vibration motor to spin. You can change these thresholds in the software files.

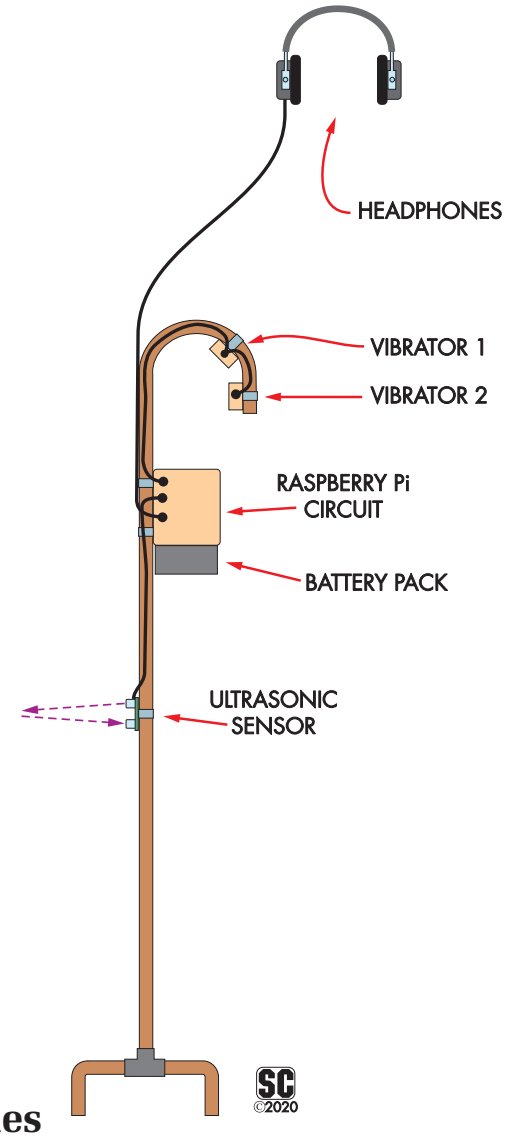
The reason for the different thresholds is to give the user an early warning when an object is first detected in their path, then a more urgent warning when they get closer to that object. The two motors can be located such that the user can distinguish where the vibration is coming from.

You can set the software to start automatically after the Raspberry Pi has finished booting by adding the following line to the bottom of the "/etc/rc.local file", before the exit line:

```
sudo python /home/pi/ultra3.py
```

The whole thing can be powered from a 6V rechargeable battery, either lead-acid battery or NiCad (4-5 cells).

Bera Somnath,
Vindhyanagar, India. ($80)



Simple "emergency" charger for small batteries

I recently needed to charge a small NiMH battery but had no charger on hand. So I quickly whipped up the following circuit using an Arduino board. Practically any microcontroller with an internal analog-to-digital converter (ADC) could be used similarly.

A low-value resistor is connected between the ADC-capable pin and the positive end of the battery. This pin must also be capable of being used as a digital output. The negative battery terminal connects to the microcontroller's ground.

The Arduino sketch works as follows. The pin is initially configured to measure the voltage, using the ADC, to determine the battery's stage of charge. The resistor has a low impedance compared to the ADC, so it does not affect the voltage reading.

If the battery is below its fully charged voltage, the pin is then driven high, putting energy into the battery via the resistor. Or, if the battery has reached its target voltage, the pin remains in a high-impedance state.

In either case, after a brief period, the pin is switched back to being an analog input and the process repeats. The Arduino's onboard LED is used to indicate whether charging is occurring or has completed. The ADC voltage can also be displayed to the serial monitor if more detailed information is needed.

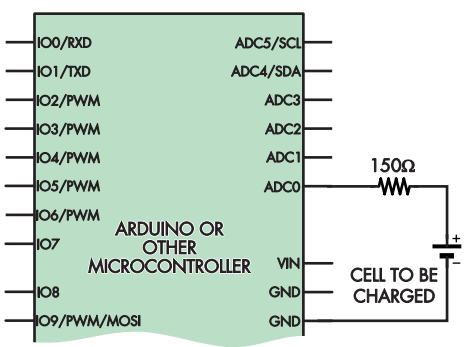
The sketch is available for download from the SILICON CHIP website. Its default threshold is 1.4V, to suit a single NiMH or Nicad cell.

Assuming a 5V microcontroller, the threshold can be adjusted to suit LiPo (4.2V) or $LiFePO_4$ (3.6V) cells, or a battery of a few NiMH or NiCad cells in series.

The resistor value should be chosen to suit your micro and battery. Determine the micro's maximum I/O pin current (40mA for an Arduino Uno and most Atmel AVR micros), then divide this by the difference between its supply voltage and the battery's minimum (fully discharged) voltage.

So for example, if the battery could be as low as 1V, for an Arduino you could use 100Ω ([5V - 1V] ÷ 40mA). We've shown 150Ω in this case to be safe, as the cell could possibly be below 1V, and the micro's supply could be a little bit above 5V. This limits the maximum current to around 33mA in the worst case.

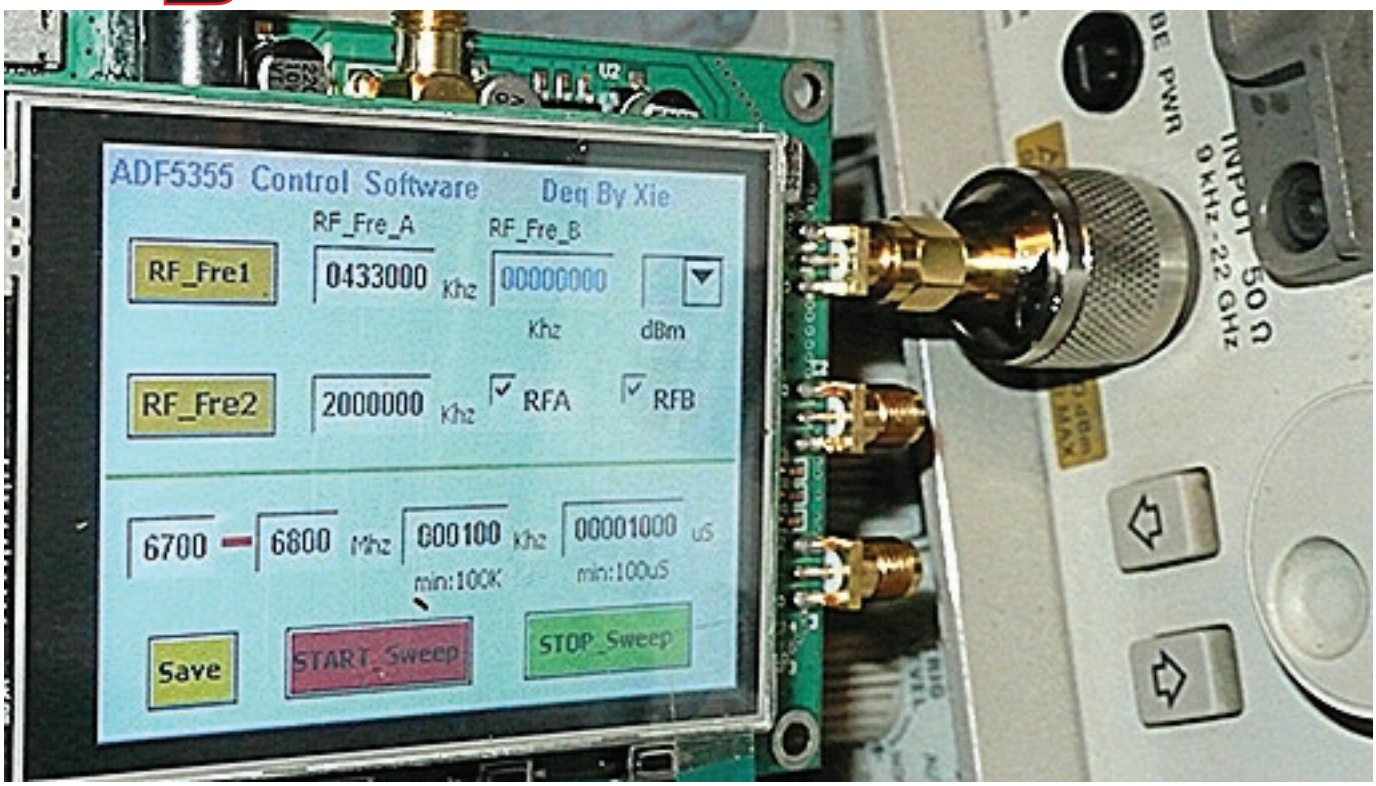
Tim Blythman,
SILICON CHIP.



Review By Allan Linton-Smith

TOUCHSCREEN

54MHz to 13.6GHz Signal Generator



Here's an excellent example of the march of technology. It wasn't that long ago that low-cost ADF4351-based signal generator modules became available. These could generate signal frequencies up to an amazing 4.4GHz. But in a little under two years, the new ADF5355-based modules go up to a whopping 13.6GHz. All this for around and $250, with touchscreen control!

These modules need no modifications or additional circuitry; just plug in a 5V DC supply or USB cable, attach your cables and go!

In this review, we'll describe the ADF5355-based unit and show you some practical applications.

This device is based around the Analog Devices ADF5355 Microwave Wideband Synthesizer (with Integrated VCO). It's paired with an SM32 colour touchscreen for control.

This chip has many similarities to the ADF4351 which was reviewed by Jim Rowe in the May 2018 issue, starting on page 82 (siliconchip.com.au/Series/306).

However, the module described back then (which cost about $30) was 'bare bones' and had no user interface; you had to build one. That isn't the case here, as this unit comes fully assembled and ready to use, as a complete (if basic) test instrument.

The ADF5355 module we obtained has four outputs. The middle SMA connector on the right-hand side delivers signals from 54MHz to 6.8GHz, while the bottom connector provides identical signals but 180° out of phase.

The top right-hand output (connected to the spectrum analyser in the accompany-

ing photo) has a signal which is multiplied by two compared to the other two. The output from this terminal can sweep from 13.4GHz to 13.6GHz in one millisecond, in 100kHz steps (as shown on the screen; remember, the frequencies from this output are doubled). I find that amazing!

The ADF5355 achieves this by having an integrated VCO with a fundamental output frequency of 3400-6800MHz. Its output goes to divide by 1, 2, 4, 8, 16, 32, or 64 circuits that allow the user to generate RF output frequencies as low as 54MHz (ie, 3.4GHz ÷ 64).

For applications that require isolation, the RF output stage can be muted, with the mute controllable via the touchscreen.

Note that you can also purchase similar touchscreen-controlled modules with the lower-spec ADF4351 chip that we mentioned above. These are available from various internet sellers for around $78 including delivery, and are a very convenient option for those who don't need to go above 4.4GHz and just want to plug in a power supply and go!

Block diagram

Internally, the ADF5355 is almost identical to the ADF4351, except that the VCO (voltage-controlled oscillator) core operates at higher frequencies, from 53MHz to 6.8GHz.

As well as dividing the VCO output frequencies by up to 64 and then sending them to RFoutA+ and RFoutA- (180° out of phase), it also multiplies the VCO frequencies by two, to create signals from 106MHz to 13.8GHz. These go to RFoutB; see the red box in Fig.1, the block diagram from the device's data sheet.

Outside this red box, the block diagram is very similar to that of the ADF4351. We described its operation in detail in the aforementioned May 2018 article, so if you want a more complete description of its operation, please refer to that article.

Note that there is no RFoutB- output, possibly because the IC is already overcrowded and the designers were seeking to achieve the maximum frequency for the minimum price.

Interestingly, the transistor count for this IC has increased from 36,955 (ADF4351) to 103,665 plus 3,214 bipolar semiconductors. That's 2.8x more transistors – so perhaps there is not much spare room!

Specifications (as per manufacturer's data sheet)

- Frequency range: 53.125MHz to 6.8GHz (outputs A) and 106.25MHz to 13.6GHz (output B)
- Accurate from -40°C to +85°C
- Low phase noise: typically -103dBc/Hz (13.6GHz, 100kHz offset)
- RF output power: 8dBm at 1GHz, -3dBm at 6.8GHz
- Programmable output power level: +5dBm to -4dBm
- Power supply: 5V DC
- Internal VCO frequency range: 3.4GHz to 6.8GHz
- Harmonic content: -22dBc (2nd harmonic), -20dBc (3rd harmonic)

We paid $248 including postage for our module – but bearing in mind that even old benchtop GHz generators can cost thousands, that's peanuts! We spotted a 20-year-old 20GHz Anritsu generator on eBay for $16,000. This module is well and truly affordable by comparison!

We connected the module's output to a spectrum analyser to check it out (see Fig.2). Sweeping over the 13.6-13.8GHz range, the output level was reasonably flat. We only measured an output level of -5.12dBm (124mV into 50Ω), but that is nevertheless very useful.

Note that the spectrum analyser trace is set on "max hold" during the sweep, to give a graph without dips. Resolution at this frequency is 1MHz, so you won't see the 100kHz troughs.

The output power from the manufacturer's data sheet, shown in Fig.3, indicates how the output level decreases as

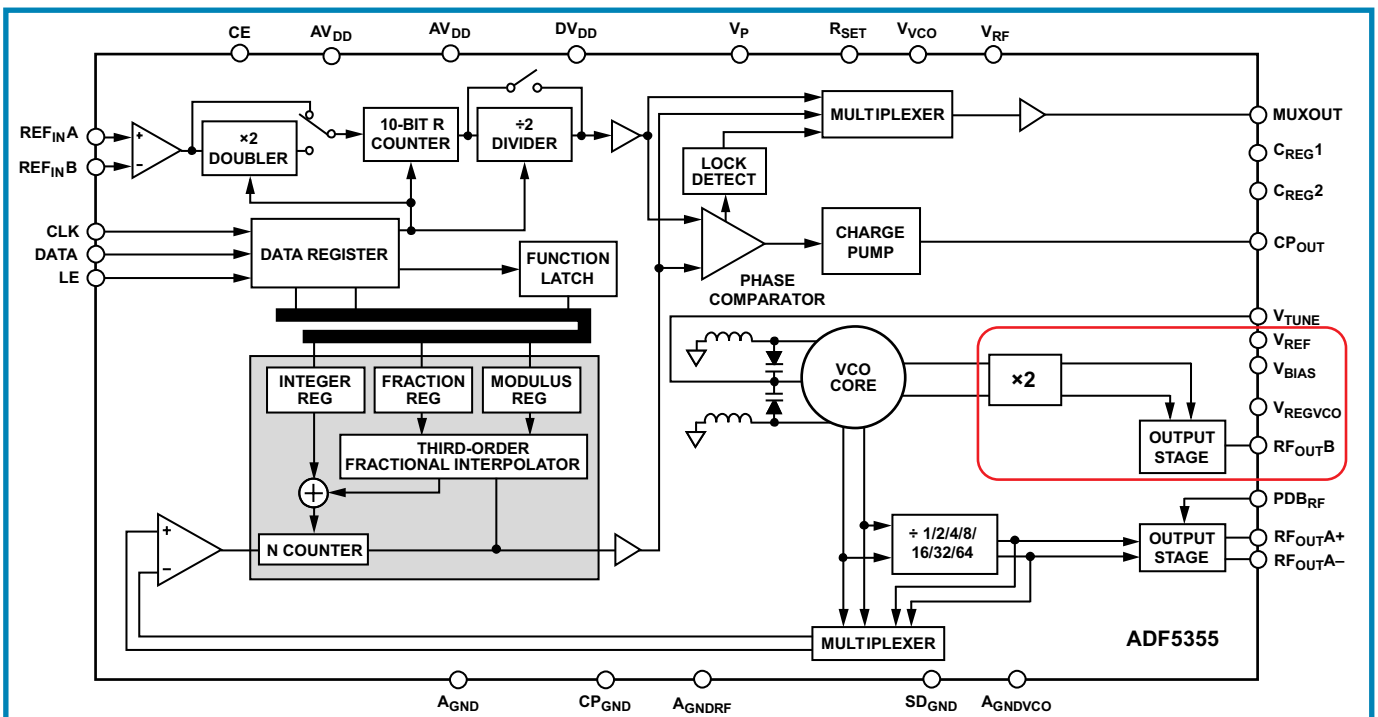
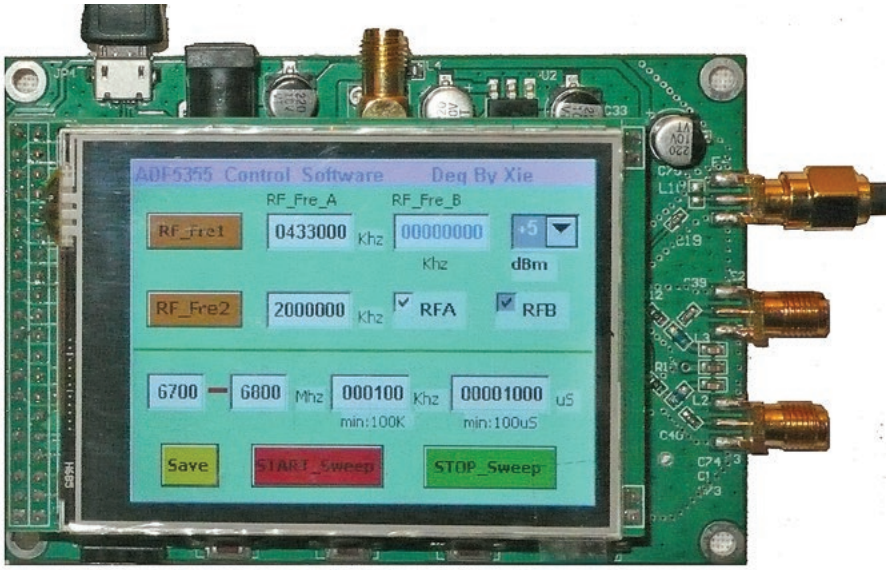


Fig.1: the ADF5355 block diagram, taken from its data sheet. Aside from the frequency doubler and extra output in the red box, it is similar to that of the ADF4351 chip described in the May 2018 issue.



The ADF5355 module we obtained has four outputs, two which go from 53.125MHz to 6.8GHz and are 180° out of phase from each other, and one which goes from 106.25MHz to 13.6GHz in 100kHz steps. All outputs can be swept across a user-defined frequency range over a period of 1ms or more.

frequency increases.

In Fig.3, we've again connected the module to a spectrum analyser (this time a more modern device) and set it to sweep from 100MHz to 6.5GHz. The markers show the amplitude at a few different frequencies over this range; again, the trace was set on "maximum hold" to give a usable graph.

Our module was pretty well in line with the specifications, but there are some additional losses at multi-GHz frequencies due to PCB layout, adaptors, connectors and cables. At these dizzy frequencies, you have to be careful to keep signal paths short!

Usability

The touchscreen is easy to use but it, and the buttons, are quite small so big fat fingers may upset the settings. The solution is to use some sort of pointer – a pencil will work. It then performs very smartly.

No written instructions accompanied our module, but we were able to extract them from a link provided by the seller. However, because they were originally written in Chinese, the English is a bit "lost in Google translation". While it is quite intuitive to use, the learning curve is still a bit steep. We will give a few hints later.

If you purchase one of these, press your seller to include a printed manual, because a lot of the feedback online is complaints about the lack of a manual.

It did, however, come with a USB power lead and four standoffs for mounting. We highly recommended that you mount the module in a Jiffy box or similar, because all the soldered connections are left bare on the PCB, and these can easily short against a metal object, which may spell D-O-O-M for your $250 signal generator.

We were very impressed with the output of this little unit; it very nearly achieves the levels specified in the Analog Devices data sheet. At these high frequencies, even a simple SMA to BNC adaptor can change the signal characteristics, either through power loss or standing waves. This may result in a sweep which is not flat and also create analytical errors when testing devices using various adaptors and connectors.

Practical applications

The manufacturer suggests that this chip could be used for wireless infrastructure, microwave links, satellite comms, clock generation, test equipment and instrumentation.

As an example of the latter, we used it to test for cable losses, by connecting the cables between the generator's output and the input of a spectrum analyser, and sweeping up to 2.5GHz.

Two three-metre cables were tested, one made of standard coax with BNC connectors and the second, a low-loss 3mm cable with SMA connectors. The results are shown in Fig.5.

You can see that the coax cable with BNC connectors loses 12dB more signal than the low-loss cable at 2.5GHz, and this demonstrates that very good cables are required at high frequencies.

This module would also be convenient

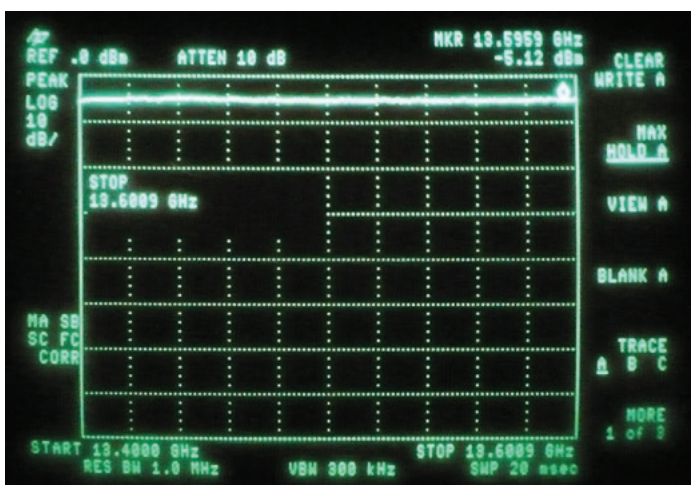


Fig.2: a spectral analysis of the module's output level when sweeping from 13.4GHz to 13.6GHz. The result is commendably flat, although the overall level is a little low at -5.12dBm (or 124mV into 50Ω). The analysis resolution is 1MHz, so you won't see the 100kHz troughs caused by the stepped sweep. (The test setup used to capture this is shown on page 84).

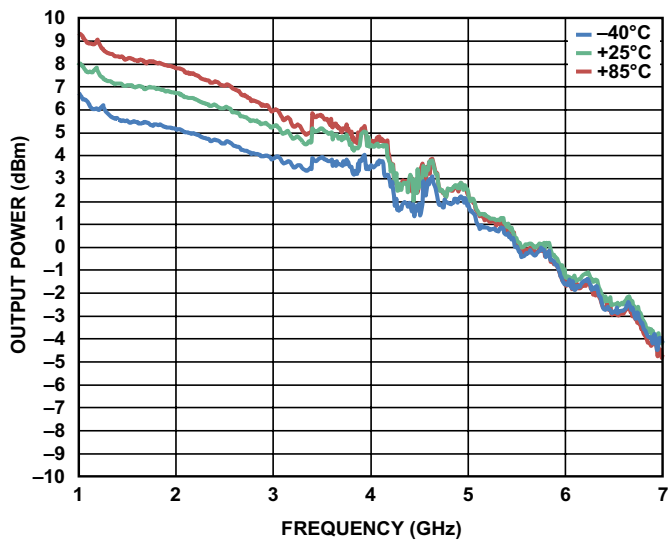


Fig.3: a graph (from the manufacturer's data sheet) showing the chip's output power. Note how the output level decreases as the frequency is increased.

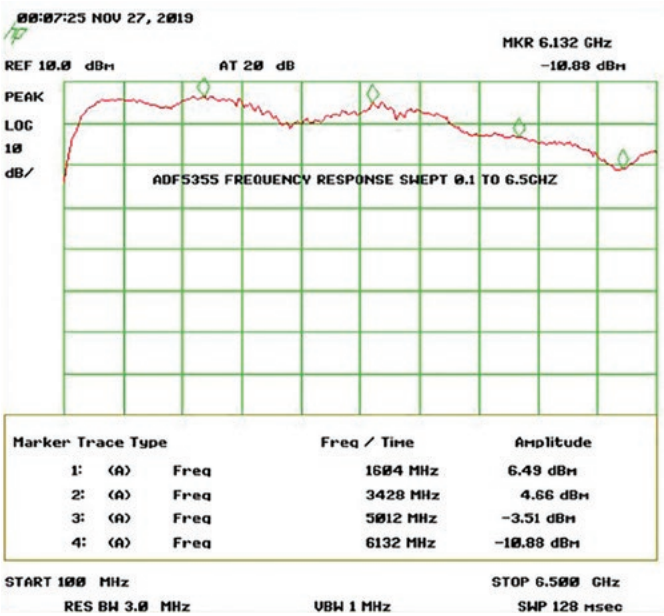


Fig.4: we set up the module to sweep from 100MHz to 6.5GHz and plotted the resulting output level on a slightly more modern spectrum analyser. It was set on "maximum hold" to give a better result. These results are not far off what Analog Devices specifies for the chip, although some small losses in the board are apparent.

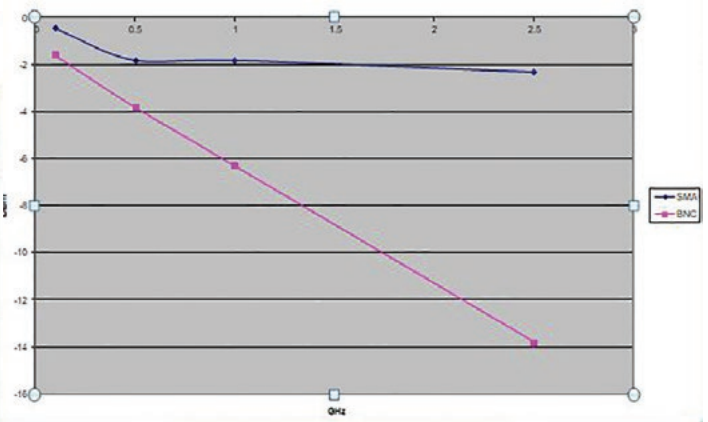


Fig.5: one practical use for this module (among many) is testing cable losses in combination with a spectrum analyser that lacks a tracking generator. Here you can see that low-loss coax (in blue) loses, err, less signal compared to the box standard coax (mauve).

for testing frequency counters and similar devices. Naturally, there are many other ways to use this module, and we leave that up to your imagination!

The future!

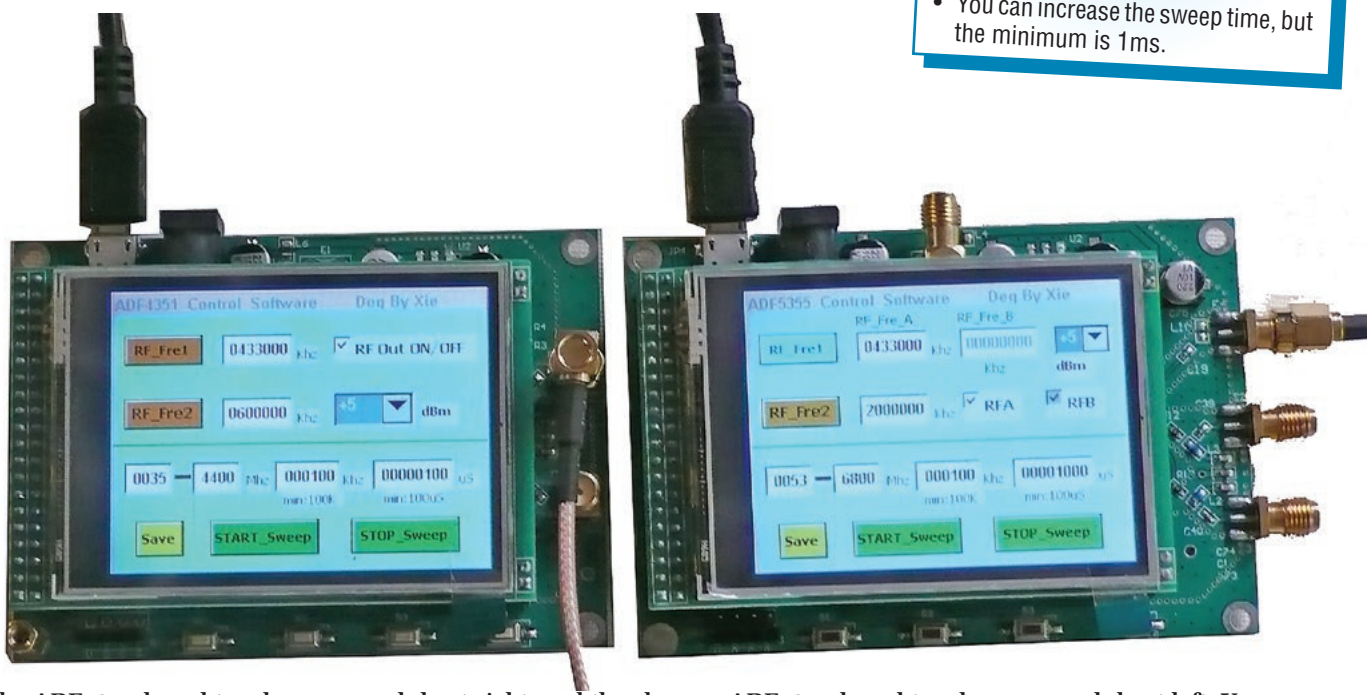
If progress continues at this pace, in two years we should have an affordable 50GHz signal generator IC. Already as we write this, there is a Texas Instruments signal generator IC available which has a higher output power and better stability than the ADF5355.

It is the LMX2594 15GHz Wideband PLLatinum™ RF Synthesizer with phase synchronisation and JESD204B support.

No doubt there will be bigger and better to come! SC

Some useful tips

- Our supplier advised us not to remove the screen cover, as the screen surface is easily scratched.
- Mount the module in a box of some sort to protect it.
- Always stop the sweep before changing any values.
- Always set the start frequency before the stop frequency.
- After using the keyboard, press Enter, then Back, and keep pressing Back until the keyboard disappears.
- You cannot set the resolution to less than 100kHz.
- You can increase the sweep time, but the minimum is 1ms.



The ADF5355-based touchscreen module at right, and the cheaper ADF4351-based touchscreen module at left. You can see that the module at right has more output connectors and a slightly different user interface.

DIY SOLDER REFLOW OVEN WITH PID CONTROL

When we left off last month, we'd finished assembling the PCBs and the hardware required. Now all that's left is to put it all together – and get it going!

Part II – by Phil Prosser

Just in case you missed the first instalment last month, let's briefly recap:

We're taking a bog-standard "toaster oven" (we bought ours at KMart) and making a controller for it, which allows it to be turned into a reflow oven for soldering PCBs with lots of (or even a few) SMD components.

We do this without any modifications to the Toaster Oven at all – in fact, there is only minimal mains wiring to be done within the controller. What's more, we've made it very safe to use.

If you want more details than that, we'd suggest you look up the first part in the April issue (siliconchip.com.au/Article/13802).

Now, let's get on with the show!

Putting it together

Everything mounts inside a commercial plastic case, with the components mounted on a baseplate made from 1.5mm-thick aluminium. Cut it to 200x115mm and drill all the required holes as shown in Fig.8. Deburr all the holes and clean it up.

We haven't shown a cutting/drilling diagram for this simply because of its size but we have prepared one; it can be downloaded from the SILICON CHIP website and printed out at 1:1 size.

Similarly, drilling diagrams for the front and rear panels, along with a cutting and drilling diagram for the Presspahn safety shield can also be downloaded. Now would be a good time to get those diagrams and cut/drill the components.

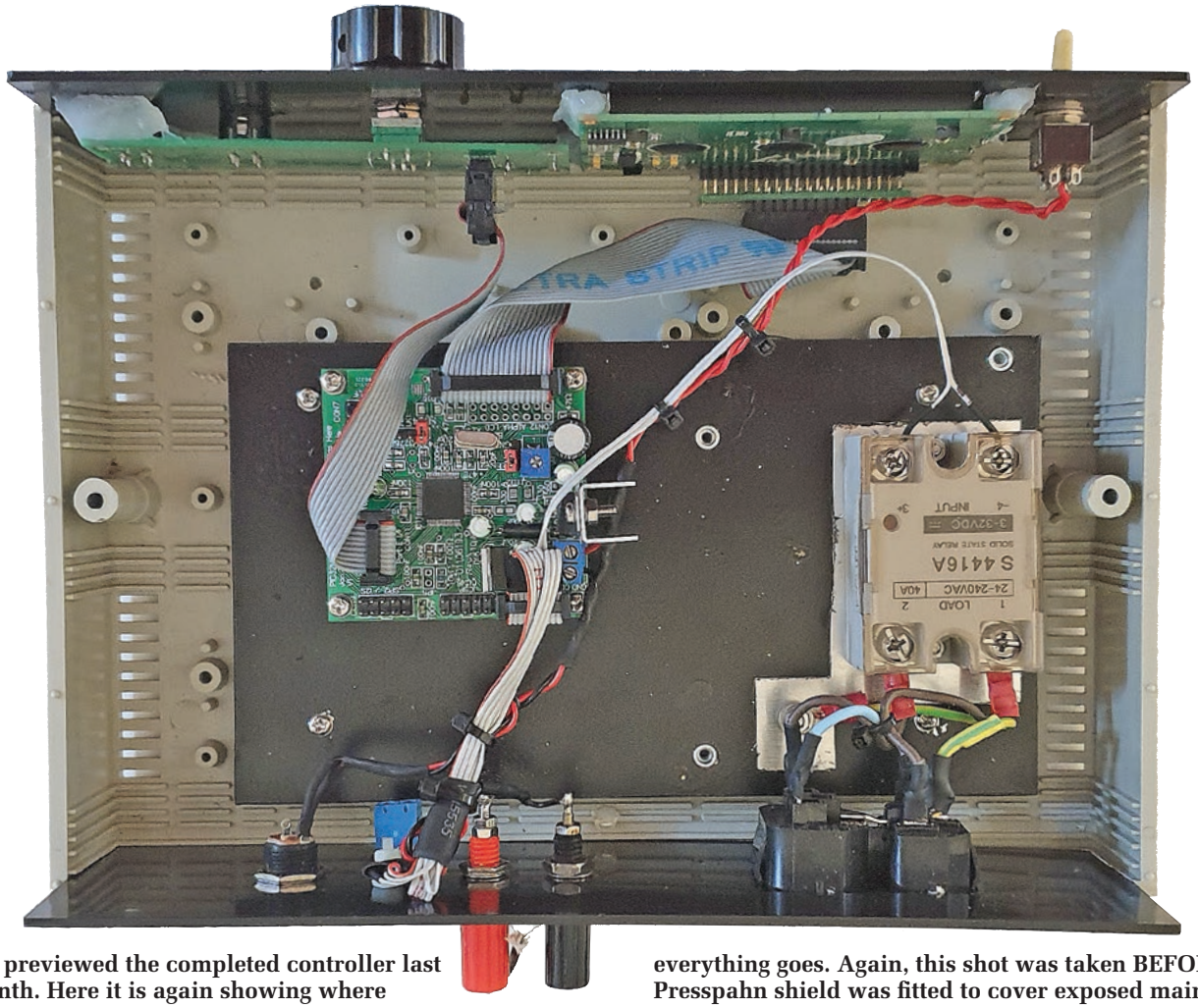
We applied masking tape to the front and rear panels and marked cuts and holes on this. For the LCD and the IEC connector, we used a Dremel with a cut-off wheel to cut just inside the marked cut lines, then used a file to neaten the holes. This gave a neat result.

Use the aluminium plate as a template in the bottom of the case, to mark out and drill the holes which will be used to attach the plate to the base.

Be careful to leave a minimum of 40mm of room to the front panel for the LCD connector.

Now you can start to fit the components to the baseplate. Apply a small dollop of heatsink paste under the solid-state relay before mounting it.

Covering the panel with masking tape before cutting out the display window has two benefits: (a) you can much more easily mark the position on the tape (along with other hole locations) and (b) it tends to make the waste stay in place, resulting in less mess!



We previewed the completed controller last month. Here it is again showing where everything goes. Again, this shot was taken BEFORE the Presspahn shield was fitted to cover exposed mains.

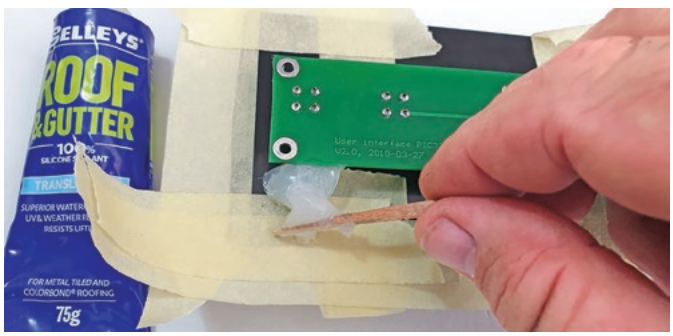
Mount the PIC32MZ PCB using 15mm Nylon standoffs. These ensure that the board is well insulated, with sufficient creepage distance from the base plate. Do not substitute metal standoffs. You can then attach the metal plate to the bottom of the instrument case and move on to the front and rear panels.

For the rear panel, attach the dual IEC connector, binding posts and DC socket securely. We can solder wires to these in-situ later.

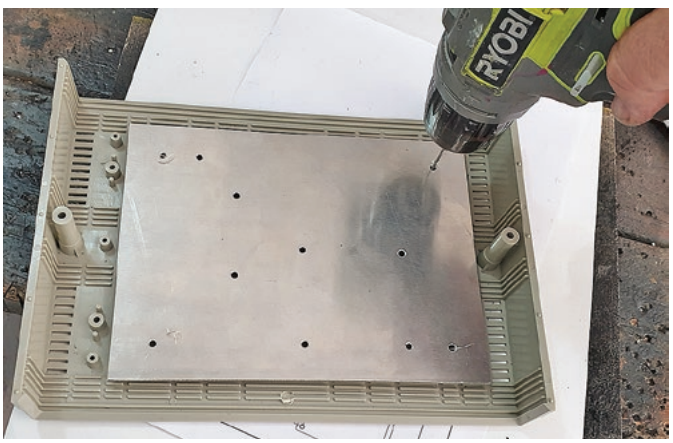
It is now time to mount the LCD screen and front panel PCB. We used glue (actually, silicone sealant) to avoid messy screws through the front panel, and makes it bombproof. You just need to be a bit careful in application. Start with the LCD.

If your cut-out leaves a gap around the LCD screen, you may be able to see the white of the backlight assembly through the gap. So use a black marker to colour in the white backlight around the edges of the LCD panel before mounting it.

Put masking tape across the front panel cut-out and temporarily mount the LCD, making sure that the connectors are on the bottom. The tape should hold the LCD pretty well flush with the front panel.



To avoid screw heads protruding from the front panel, we glued the LCD to the rear of the panel using silicone sealant. The masking tape showed us where the glue was to go.



Once you've drilled out the baseplate (download the PDF from siliconchip.com.au) it can be used as a template for drilling the four required holes in the case (these align with four of the pillars moulded into the case).

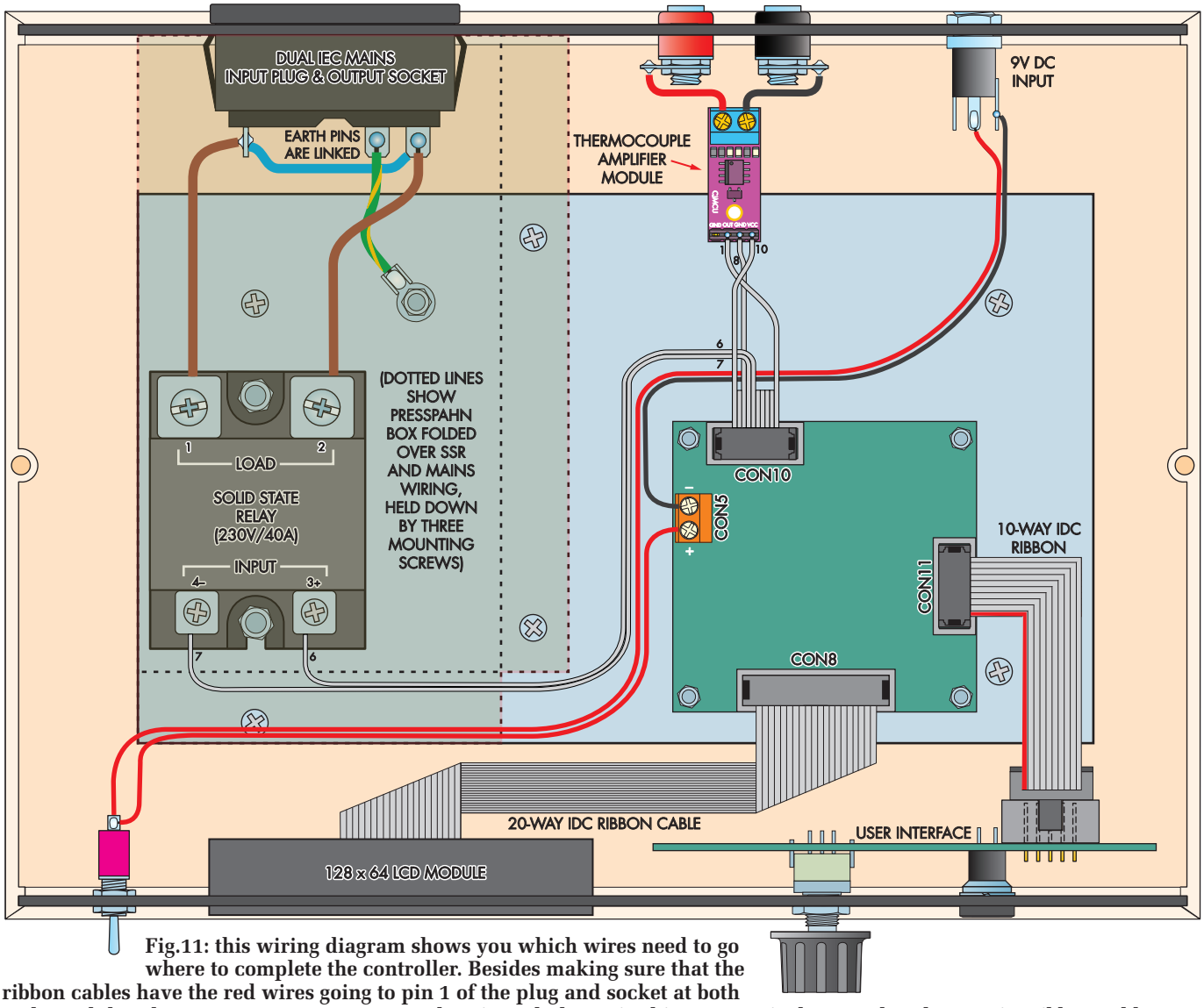


Fig.11: this wiring diagram shows you which wires need to go where to complete the controller. Besides making sure that the ribbon cables have the red wires going to pin 1 of the plug and socket at both ends, and that the IDC connectors are correctly crimped, the main thing to note is the way that the 10-wire ribbon cable from CON10 is split up and routed to two places. Only five wires in this cable are used; the other five should be cut short. When finished, use cable ties to tie all the bundles of wires together, so nothing can move around, and don't forget to add the Presspahn barrier.

Also, apply masking tape around the LCD edges to facilitate tidying up the silicone after you have applied it. Refer to the accompanying photo.

Next, attach the front panel control board. Put one nut (or several washers) over the rotary encoder shaft to set a minimum depth, then mount it to the front panel using the supplied nut. Check the pushbuttons operate properly and do not get stuck on the front panel. If they do, carefully file the holes a bit larger with a round file.

Once it is all good, tighten up the nut on the rotary encoder and check that everything is sitting neatly. Adjust if necessary.

Then, using a matchstick or small timber offcut, build up a dollop of silicone at either corner of the LCD. Do the same with the control board, at the end far from the rotary encoder. Watch out for the pushbutton; do not get silicone onto this, or it will stop it working. You do not need to use a lot of silicone – a dollop at either corner is more than enough. We used far more than necessary.

Once the silicone has set, attach the on/off toggle switch in the usual manner, and push a knob onto the rotary encoder. You are now ready to start the wiring.

Wiring it up

Fig.11 shows the wiring that's needed to finish the controller. As you do the wiring, keep in mind that twisting pairs or bundles of wires together and/or covering them in heatshrink tubing will keep the whole thing neat.

Importantly, this also contributes to the safety, as it stops wires that might break off from moving around and contacting other parts of the circuit.

See our photos for an idea of what it should look like when you've finished.

Start by running light-duty red hookup wire from the middle pin of the barrel connector to the front panel on/off switch, then from the other terminal of the on/off switch to the + power input of the PIC32MZ controller board. Run light-duty black wire from the DC socket ground (outer

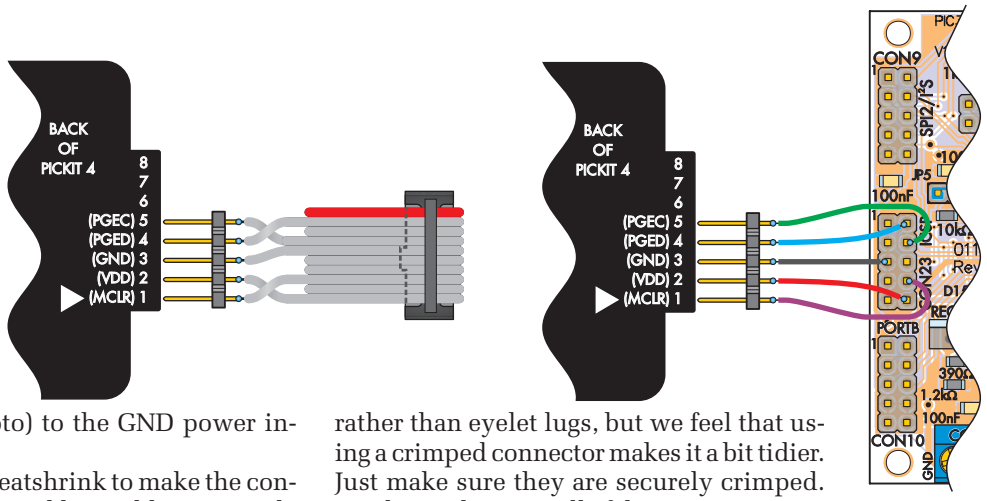


Fig.12: PIC32s purchased for this project from our online shop come pre-programmed, but if you're using a blank micro or there is a firmware update, here is how to connect a PICkit 3/4 or similar to the board to reflash the chip.

connector, as shown in the photo) to the GND power input of the PIC32MZ.

Twist these together and use heatshrink to make the connections tidy. Then plug in the two ribbon cables you made earlier, one from the CON11 on the CPU board to CON2 on the front panel, and the other from CON8 on the CPU board to the DIL header on the back of the LCD adaptor board. In each case, make sure the red stripe side of the cable goes towards the pin 1 side on the connector.

Hopefully, when you soldered the LCD adaptor to the LCD screen earlier, you connected pin 1 on that board to pin 1 on the LCD. If not, rotate the IDC connector plugging into the LCD adaptor by 180° to compensate.

The specified dual male and female IEC connector allows a conventional IEC mains power cord to supply power to the unit, and also makes it easy to connect up to the oven.

Strip out a length of 10A mains flex or an unused 10A-rated mains power cord to get the brown, light blue and green/yellow striped wire that you will need to wire this up to the SSR.

For the following mains wiring, keep all the wires as short as possible to maximise safety (the Earth wire is less critical, but it's still better to keep it short if possible.)

Use a short length of the light blue wire to join the two Neutral connectors on the socket together. These are both marked with an "N". Then crimp an eyelet lug onto one end of a short length of green/yellow striped wire, solder the free end to the Earth connector on the mains socket and attach the eyelet to the baseplate using a machine screw, a shakeproof washer (under the eyelet) and two nuts.

Cut two lengths of brown wire and crimp eyelets to one end of each, then solder the free ends to the incoming and outgoing Active terminals on the mains connectors. It doesn't matter which wire goes to which load terminal on the SSR - this is AC after all, so current must be able to flow in both directions.

Note that you could connect to the SSR using bare wires rather than eyelet lugs, but we feel that using a crimped connector makes it a bit tidier. Just make sure they are securely crimped. Apply insulation to all of these connections, and double-check them, then cable tie them all together, so that if one comes loose, it can't go anywhere.

Thermocouple input wiring

The two binding posts are mounted 20mm apart, allowing the Jaycar QM1284 thermocouple to be plugged straight in. This provides a professional-looking solution. However, as mentioned earlier, if you run the thermocouple wire through a grommet in the rear panel and connect them directly to the screw connectors on the thermocouple amplifier board, the temperature readings will be more accurate.

The downside is that you now have a captive thermocouple wire, so changing the thermocouple is a tedious job.

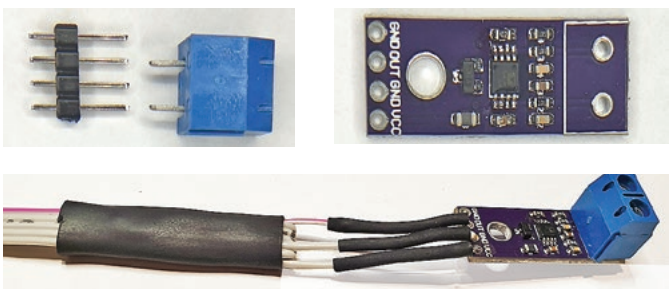
The thermocouple and also the Solid State Relay signals connect to CON10 (PORTB) on the PIC32MZ board. We suggest that you crimp an IDC connector onto one end of a length of 10-way ribbon cable. This can then be plugged into CON10 and the wires at the other end separated and stripped to make the required connections. Make sure that the red striped wire goes to the IDC terminal marked as pin 1.

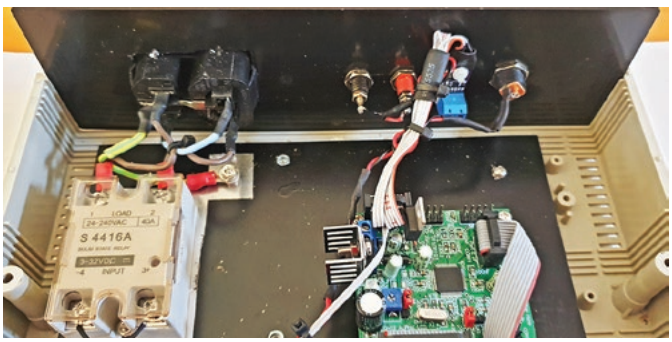
With this cable, some fiddling is required. We couldn't think of an easier way for this short of adding a PCB, which seemed over the top. Pull the wires apart to separate out wires 1 (red), 6 & 7 (together), 8 and 10. Snip the other wires off short as they are not needed. Mark wires 7 and 8 as "-" with some heatshrink or colour it with a permanent marker.

Connect wire 6 to the solid-state relay input + terminal, and wire 7 to the SSR – input. These can be wedged under the screw terminals; do them up tight.

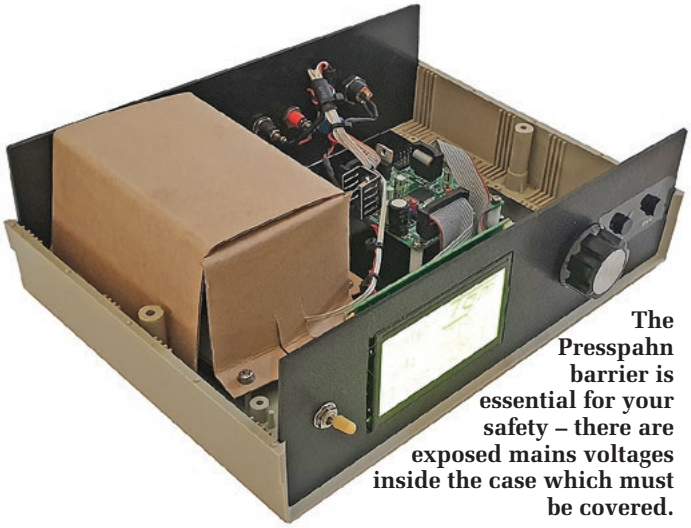
Connect wire 1 to the "Out" connection of the thermocouple amplifier, wire 8 to its ground and wire 10 to the positive power input on the thermocouple amplifier.

The thermocouple amplifier we used has a purple PCB. If you search ebay or AliExpress for "AD8495", then you should be able to find one which looks like ours.





A view of the rear panel connections – again, this is before the Presspahn insulation barrier is installed. Don't forget it!



The Presspahn barrier is essential for your safety – there are exposed mains voltages inside the case which must be covered.

A male IEC plug to female mains socket (such as this on from Jaycar) means no modifications are required for the toaster oven.

We arranged the cable lengths so that it is possible to encapsulate the thermocouple amplifier in heatshrink tubing and zip tie it to the binding posts. This places the thermocouple amplifier in reasonable contact with the thermocouple plugs. Remember that this amplifier has correction circuitry that accounts for the temperature of the thermocouple plug, so the closer it is to this plug, the better.

If you've purchased the recommended thermocouple amplifier with purple PCB, there will be a mounting hole. You can use this to mount it to the rear panel with a Nylon machine screw and nut, close to the binding posts/banana sockets.

Tidying it up

Once you've finished all the wiring, use cable ties to tie each bundle of wires together. This is especially important for the mains wiring, which must all be tied together securely, and also the red and black wires from the DC socket to the front panel on/off switch and to CON4 on the control board.

Make sure that these wires are tied so that they can't move around inside the case (eg, by tying them to the nearby ribbon cables) and that if one breaks off at either end, it can't go anywhere.

Now is also a good time to attach the Presspahn insulation barrier to the bottom plate using machine screws, shakeproof washers and nuts. Refer to the photos to see where it goes. Once the lid is on the case, it should isolate the mains section from the rest of the controller.

Initial testing

For the following tests, do not connect the mains lead. Use only the 9V plugpack. Make sure that jumper JP5 on the CPU board is inserted. There must also be a jumper on LK2 in the position shown in Fig.4. You don't need a jumper on LK1; if there is one there, it doesn't matter which position it is on.

Now switch the device on and check the LCD. Adjust the LCD bias voltage using trimpot VR1. This may require some experimentation; the LCD will initially show no image or a washed-out image. Adjust the bias from one end toward the other until you get a good image.

Next, check that the user controls work by press the right-hand button (EXIT); a screen with four boxes should appear. Rotate the encoder knob; you should see each of the four quadrants be highlighted in turn.

Now we set the initial PID coefficients. Pressing the left-hand button/rotary encoder knob (SEL) when the "adjust PID settings" screen is highlighted. You will be presented a screen asking if you are sure. Rotate the dial to "Yes" and click SEL. Enter 100 for P, 0.5 for I and 670 for D.

This configuration is super critical – if you do not do this, the thing will most likely show 0° C, and definitely not work.

Next, set the reflow settings by pressing SEL when the "Setpoints" screen is highlighted. You will be presented a screen asking if you are sure. Rotate the dial to "Yes" and click SEL. Enter 150C for Preheat Temp and 225C for Reflow Temp.

Four holes must be drilled in the front panel (follow the drilling diagrams on siliconchip.com.au) but there is also a cutout required for the display. We used a Dremel to cut out the rough hole then finished it off with a fine file. The same system can used for the IEC mains socket cutout on the rear panel.

Pin	Role	Connect to
1	Analog input	Thermocouple amplifier output
6	Heater control	SSR input 3+
7	GND	SSR input 4-
8	GND	Thermocouple amplifier GND
10	+3.3V	Thermocouple amplifier power supply

Table 1 – CON10/PORTB connections (other pins not used)

Then set the Sensor TEMPCO settings by pressing the left button (SEL) when the "Tempco and Offset" screen is highlighted. You will be presented a screen asking if you are sure. Rotate the dial to "Yes" and click SEL. Enter 0 for OFFSET (this is in °C), and 0.161 for TEMPCO.

Check that the home screen now shows approximately the right ambient temperature. Boil a jug of water, insert the thermocouple and check that the home screen shows something close to 100°C. Remember that thermocouples are not super precise devices, and an error of a few degrees is OK.

To check that the SSR drive is working, use the following steps:

1) Reset the system by cycling the power

2) Set the target temperature a bit above ambient temperature

3) Watch the LED on the solid-state relay (it is next to the input). This should light up every few seconds, in time with the lightning bolt on the screen going from an outline to a full lightning bolt

4) Turn the set temperature down to around 20°C, and hold the tip of the thermocouple between your fingers, so the measured temperature is above the set temperature

5) Check that after a few seconds, the lightning bolt and red led on the solid-state relay stop lighting.

Note that with a PID controller, there can be a lag in its response to changes in temperature and settings.

Live testing

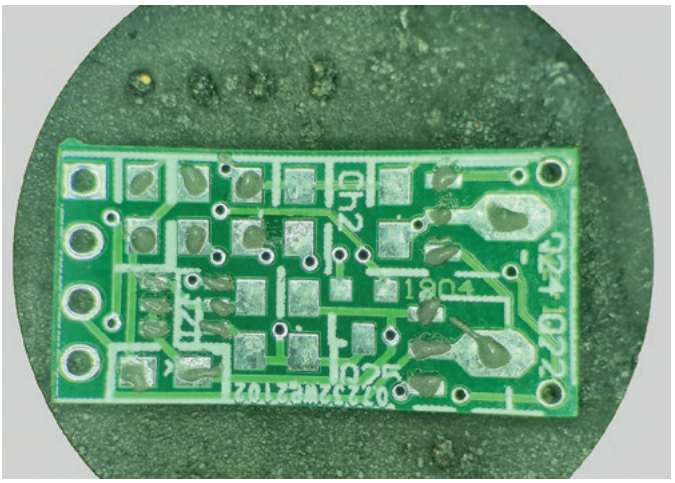
You can now switch off the power and connect the oven to the IEC mains output socket on the controller via the IEC/mains socket adaptor.

Before connecting the mains input IEC lead, double-check your wiring, and ideally have a friend triple check it. Check that:

- no daggy wires are poking out of crimps, terminals and insulation
- there are no wires stripped too far, leaving lots of exposed copper that could contact something.
- the IEC "N" connector goes to the other IEC "N", diagonally across the connector.
- the Earth connector is solidly connected to the base plate.
- one wire from each of the IEC "A" pins goes to one SSR "LOAD" terminal.

Close the case and securely screw it together; make sure there are no exposed mains wires. Turn the oven to its maximum temperature setting, and switch on all elements. Dial the timer for 20 minutes or so, plug the oven into the controller, power up the controller and set the temperature to 20°C. Plug the controller into the mains and switch it on.

The oven should not be on yet, unless your house is particularly cold. Turn the dial on the controller for a setting of 40°C. You should soon see the lightning bolt on the controller coloured in, indicating the hearer is on. If your oven is like ours, you should see a light on the oven indicate it is switched on. After a few seconds, you should see the measured temperature start to creep up.



The board used during reflow test, showing solder paste applied to pads. The amount shown here is more than enough!

The rear panel sports the 9V DC input socket (left) with the polarised thermocouple terminals alongside. At the right end is the twin IEC mains output/input socket which is the raison d'etre for this project: mains comes in to the right-hand (male) socket; controlled mains to the toaster oven comes out of the left-hand (female) socket.

Help, it's not working!

Nothing on the LCD screen

- Check that the LCD bias pot is set correctly. Turn it fully anti-clockwise, then slowly turn it clockwise until you see something on the display.
- Check that the microcontroller is running
- Check your parts and soldering, especially looking for bridges across the microcontroller pins.
- Check the output of the 5V and 3.3V regulators.

My oven is going crazy

- Have you used an oven with a smart controller? This project won't work with it!

The temperature readings are very wrong

- Is the thermocouple connected backwards
- Are the tempco and offset in the software right for your amplifier
- Use a DVM to check the voltage on the thermocouple amplifier output. It should be about 1.25V. If not, read the panel on thermocouple amplifiers
- Put the thermocouple tip in a cup of hot water. Watch to see if the voltage increases.

The temperature readings are slightly wrong

- Is your thermocouple in the oven next to your workpiece
- Check the thermocouple tempco and offset is correct for your thermocouple
- Try putting the sensor tip in iced water and boiling water. If the readings are off by more than a few degrees, check for construction errors

The oven won't heat

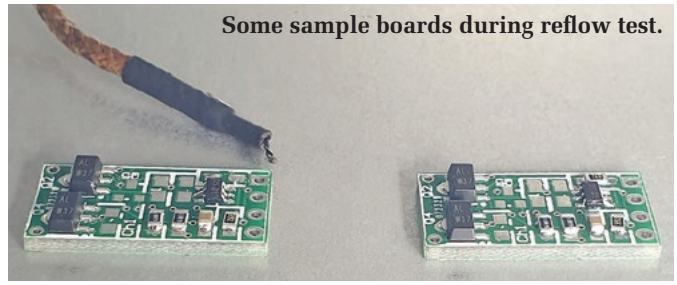
- Ummm - you did check that the oven worked normally before making any modifications, didn't you? (!!)
- Check that your oven's temperature is set to maximum and that it is switched on and both heating elements are selected.
- Is the thermocouple reading the right temperature?
- Set the temperature on the controller for say 100°C and watch the SSR. It has a red LED that indicates when it is on.
- Watch your oven power light. Is it switching on in unison with the SSR light?

The oven is running too hot when set for fixed temperatures

- At low temperatures, even with the optimisations we made, the thermal mass of the oven means that there is still a lot of overshoot. Also, the thermal mass of the elements and oven means it takes a long time to cool down.
- Try starting it up in advance and give it time to settle before using it.

Settings are lost at power-off

- Use the save option after making changes.
- Check the PIC microcontroller pins for shorts on the side close to the EEPROM
- Check the orientation and soldering of the EEPROM chip.



Some sample boards during reflow test.

The thermal inertia of the oven will cause a delay of 20 seconds or so; the temperature will likely overshoot the target. As explained above, our controller is optimised for high temperatures, and you will see overshoot in the order of 15°C or so at low temperatures. Just watch to see that heating switches off before it reaches the target temperature.

Try setting the controller to 60°C, and watch the controller switching on and off. Once heated, the oven takes quite a while to cool down. Remember that when reflowing, you must open the door at the end of the cycle.

Reflowing

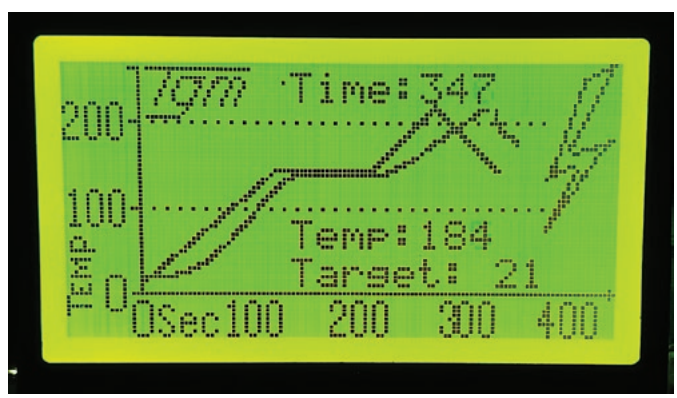
We reflow soldered a couple of boards with SMD components to demonstrate the operation of the oven. As shown in the pictures below, if you are applying solder paste by hand, use a syringe and put less than you think it will take! The biggest mistake most people make when reflow soldering parts is to add too much solder paste.

We stuck the thermocouple to the edge of the oven using tape, and fiddled it until the thermocouple was close to the test PCBs. You need the sensor to be as close as possible to the boards (maybe even touching), to ensure the temperature profile achieved is right in the vicinity of your board.

The temperature profile that the oven ran is shown below. You can see that the temperature fell after we opened the door a crack. We left it like that for about 20 seconds, then opened it fully to allow the board to cool. Don't move the board until it cools, as the solder will still be liquid for a while!

At about 180°C, the flux activates and the solder starts to reflow. By the time the oven hit 225°C, and we opened the door, the board had fully reflowed and settled down. Ideally, you should give your oven a trial run on a less-critical PCB before soldering anything really expensive.

But if you have a hot air rework station, you can probably fix anything that goes awry on the first couple of tries, until you get it fully dialled in. SC



Reflow display showing target and actual temperature profiles.

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VINTAGE RADIO

Toshiba 9TM-40 “robot” radio

By Ian Batty

Where could a portable radio that looks like a robot have possibly come from? Japan, of course. This 9-transistor superhet radio from 1961 even comes with its own leather case.

Early transistor radios followed safe design principles: a rectangular layout, thumbwheel tuning with engraved markings or a dial behind a cutout window and a thumbwheel volume control. But cranking out functional design after functional design can quickly become tedious.

While some people look for a gizmo which encapsulates the latest advances in electronics, many consumers are more attracted to eye-catching designs.

Toshiba, lagging Sony in transistor radio technology by a few years, decided that they could get a leg-up by taking a more unusual visual approach. Their 6TR-127 looked pretty much like a small valve portable with a top-mounted tuning scale and a circular speaker grille on the front.

Come the Swinging Sixties, we got the visually spectacular 7TH-425 wall radio that I described in the March 2020 issue (siliconchip.com.au/Article/12589). We also got this quirky 9TM-40, known to some collectors as the “Robot Radio”.

Japanese comic books, generally known as manga, brought Astro Boy to the world in 1952, which was broadcast on TV in 1963 (1965 for Australia). The 9TM-40 also has clear references to the robot/cyborg aesthetic.

And the addition of a pushbutton light to illuminate the dial, a kickstand for convenient use on flat surfaces and a leather case meant that this set was practical, not just pretty, An earphone/external speaker socket is pretty standard on portable trannies, but a microphone input socket is not. This allows the 9TM-40 to be used as a mini public portable address (PA) system!

Toshiba Design Studio

The 9TM-40 is unique, but it isn’t Toshiba’s only standout design. Among others, there’s the 6TR-92 “Rice Bowl” pictured below.

The 9TM-40 is reasonably hefty for a portable; it certainly isn’t a shirt pocket set.

It isn’t just an interesting looking design; it’s also very functional. The tuning dial is large and easily read, with the thumbwheel driving the tuning through a reduction drive. So tuning is easy and precise. With the tuning thumbwheel on the right and volume on the left, it’s a natural two-hander.

Circuit description

The circuit for this set is shown in Fig.1. I’ve used the SAMS components numbering to reduce confusion, in case readers have copies of the SAMS circuit for this set.

RF amplifier X1 is a germanium 2SA72 in a four-lead can. It’s a drift-field type, the third generation of junction transistors that used graded doping across the base for better high-frequency operation.

Another unique Toshiba design is the 6TR-92 “Rice Bowl” from 1959.

These devices exhibited lower feedback capacitances than their alloyed-junction predecessors, so this stage can operate without the neutralisation usually seen even in alloyed-junction intermediate frequency (IF) amplifiers. The fourth (shield) lead on the 2SA72 also reduces feedback capacitance.

The circuit begins with the tuned, tapped ferrite rod antenna. The secondary (bypassed to ground by 50nF capacitor C9) connects via 10kΩ resistor R3 to the AGC line. As X1 is an RF amplifier, this first stage of the 9TM-40 is gain-controlled. Such variable bias would be disastrous if applied to a converter, as the alterations in bias conditions would push the local oscillator off-frequency when a station was tuned in.

X1’s collector feeds a tap on the tuned primary of RF transformer L2, with the entire primary shunted by 180kΩ resistor R5. It’s there to ensure moderately wide bandwidth by reducing the Q of L2, so that small misalignments between L1 and L2 don’t compromise the set’s front-end gain.

L2’s secondary feeds 2SA52 converter X2, a similar transistor to the OC45. This part of the circuit uses base injection, similar to that used in the previously described 7TH-425. In fact, the rest of the front end is similar from here on. In common with compact transistor sets, the tuning gang uses a plastic dielectric rather than air spacing, with a cut-plate oscillator section removing the need for a padder.

The only difference here is the three-gang construction due to the added RF stage (one gang each for tuning the antenna, RF stage, and converter).

X2 operates with the usual minimal bias, ensuring that it is into cutoff over

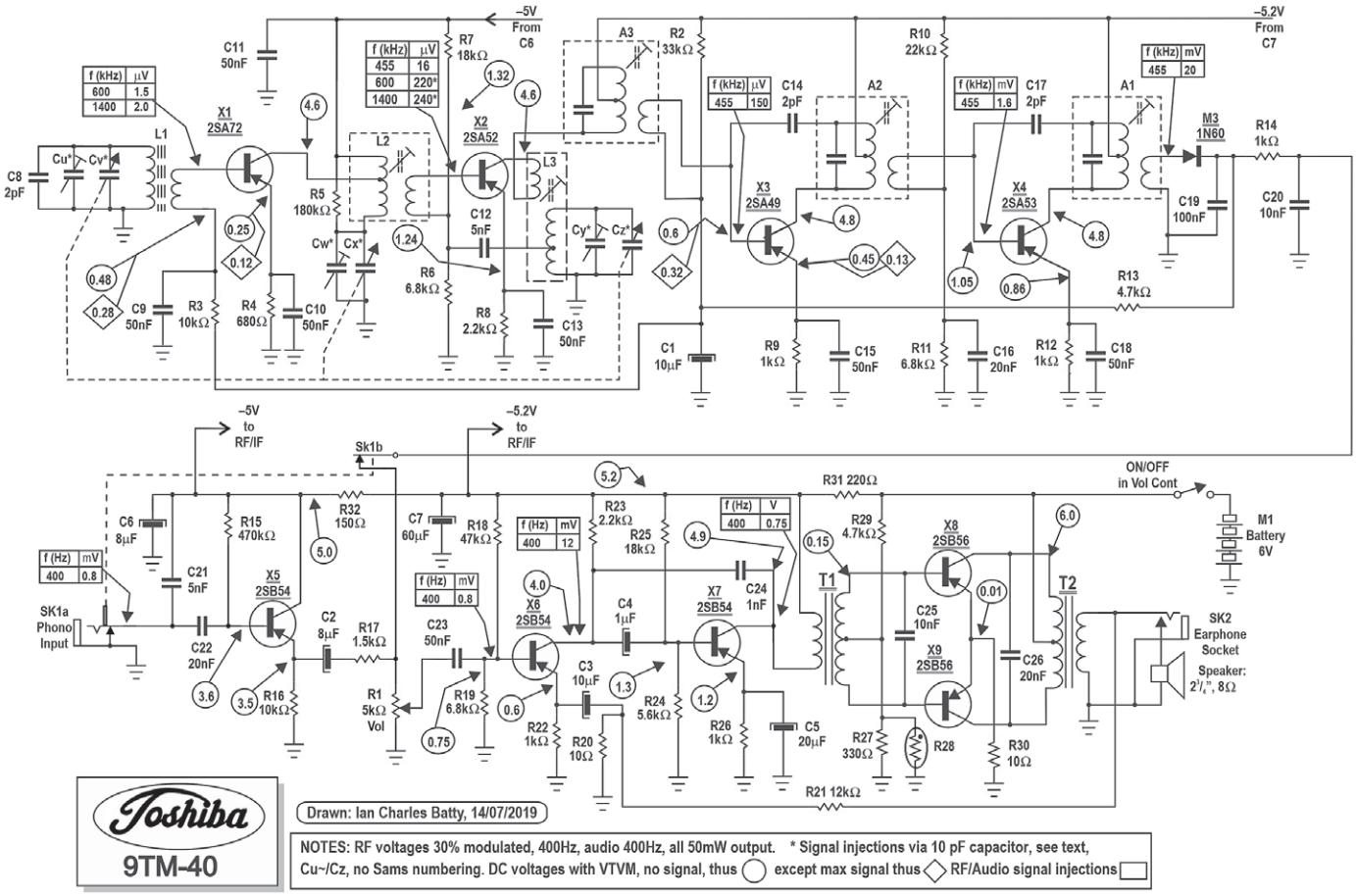


Fig.1: the circuit diagram for the Toshiba 9TM-40 shows a grand total of nine germanium transistors, quite a lot for a portable set. The 6V battery is used to derive -6V, -5.2V and -5V rails for the circuit, with a separate 1.5V battery used to power the dial lamp.

part of the local oscillator's cycle so that it can provide mixer action.

The 455kHz signal is developed across the tuned, tapped primary of the first IF transformer, A3. Its untapped, untuned low-impedance secondary feeds first IF amplifier (X3), a 2SA49, also similar to the OC45. It's an alloyed-junction type with significant collector-base capacitance.

Neutralisation is therefore applied from its collector to base by 2pF capacitor C14. X3's collector feeds second IF transformer A2's tapped, tuned primary.

A2's untuned low-impedance secondary feeds second IF amplifier X4, a 2SA53, again similar to the OC45. It also has significant collector-base capacitance. Neutralisation is applied from its collector to base by 2pF capacitor C17.

As usual for second IF amplifiers, this stage has a fixed bias. X4's collector feeds third IF transformer A1's tapped, tuned primary, and A1's untuned, untapped secondary feeds demodulator M3, a 1N60 diode. M3's output goes via the IF-rejecting low-pass filter C19-R14-C20 to volume pot R1.

The DC voltage at M3's cathode feeds the AGC line via R13 (4.7kΩ), with the AGC voltage filtered by 10µF capacitor C1. It goes to the base of the first IF amplifier transistor, X3. Forward bias for the RF amplifier (X1) and first IF amplifier (X3) transistors is provided by 33kΩ resistor R2 from the positive rail, counteracted by the AGC voltage.

Increasing signal strength will therefore reduce the forward bias on X1 and X3, and thus their gains. Unlike the 7TH-425's first IF amplifier, X3 is not decoupled from the supply to operate an AGC extension diode. This is not needed, as the application of the AGC control signal to both of these stages gives satisfactory overall AGC action.

A five-transistor circuit handles audio amplification. The microphone/phono input is buffered by the high-impedance emitter follower formed using X5, an alloyed-junction 2SB54 (similar to the AC125, which was the successor to the OC71).

As the two screws on the front panel were easily over tightened, it was common for this panel to crack.

Using simple series-bias from 470kΩ resistor R15, its high input impedance of around 135kΩ is hinted at by 20nF input coupling capacitor C22, a low value you'd expect to see in a valve circuit, but not a transistor set. Note that the SAMS circuit shows incorrect voltages at the base and emitter of X5, corrected in Fig.1.

Plugging a 3.5mm jack into SK1 disconnects the audio stage from the RF/IF section's demodulator and allows only the mic/phono signal to feed 5kΩ volume control R1, via C2 and R17.

In the main audio section, preamp and driver transistors X6/X7 (both 2SB54s) operate with combination bias. X7 has top-cut feedback applied, between its collector and base, via 1nF capacitor C24. X7 drives the primary of phase-splitter transformer T1, and T1's secondary feeds anti-phase signals to the low-impedance-base output transistors X8 and X9.

These are both 2SB189s, similar to the OC74. Shared 10Ω emitter resistor R30 helps to equalise the gains of X8 and X9, as well as providing some local negative feedback. The bias circuit, comprising 4.7kΩ resistor R29 and 330Ω resistor R27 (in parallel with thermistor R28), provides about 150mV of Class-B bias for X8 & X9. The quiescent (no-signal) current is about 5mA through this pair.

More top-cut is applied between the two output bases (10nF capacitor C25) and collectors (20nF capacitor C26).

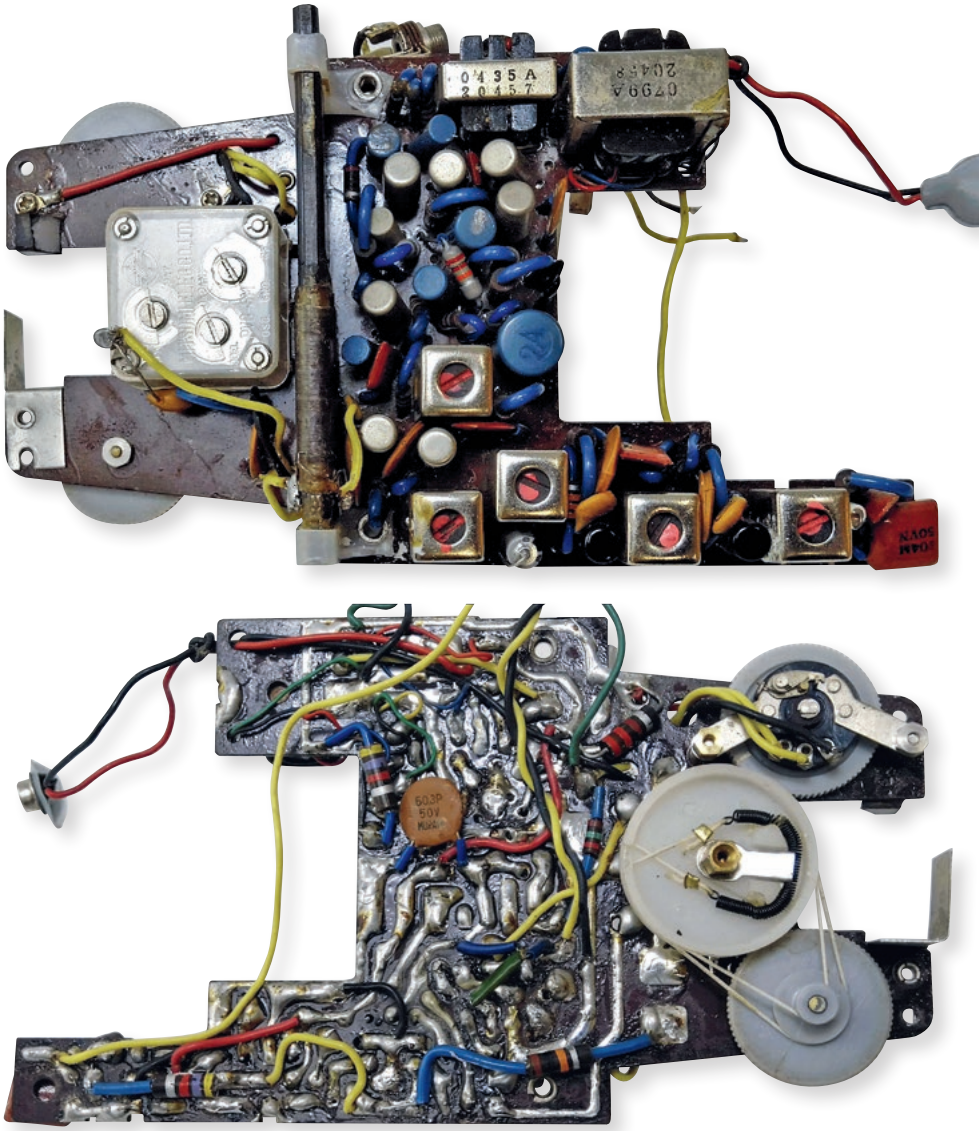
The output transistor collectors drive the primary of output transformer T2 in a push-pull manner, which provides conversion to a single-ended signal for driving the speaker voice-coil, and also matches to its impedance.

T2's secondary also applies feedback via 12kΩ resistor R21 to the emitter of preamplifier transistor X6. Unlike in the 7TH-425, the audio section's response due to feedback is designed to be flat.

Earphone jack SK2 is a simple change-over between the internal speaker and an external earphone or speaker.

Cleaning it up

I acquired this set unexpectedly. Having left my car at a local garage for service, I popped into a nearby second-hand shop. And there was this set! I'd seen one in as-new condition complete with display box and microphone for around US $600 online, but I managed to snap this one up for a fair bit less. Not quite the 'roadside emporium', but a nice find nonetheless.



The top of the 9TM-40 (above) is packed tightly with the majority of the components. The underside has a few loose components and the gears for the volume (which also acts as power) and tuning control (lower two gears), both adjusted via the side of the case.

It was a bit scrappy, with the common problem of cracking around the two top screws holding the dial. The case was worn but complete, and importantly, it worked.

How good is it?

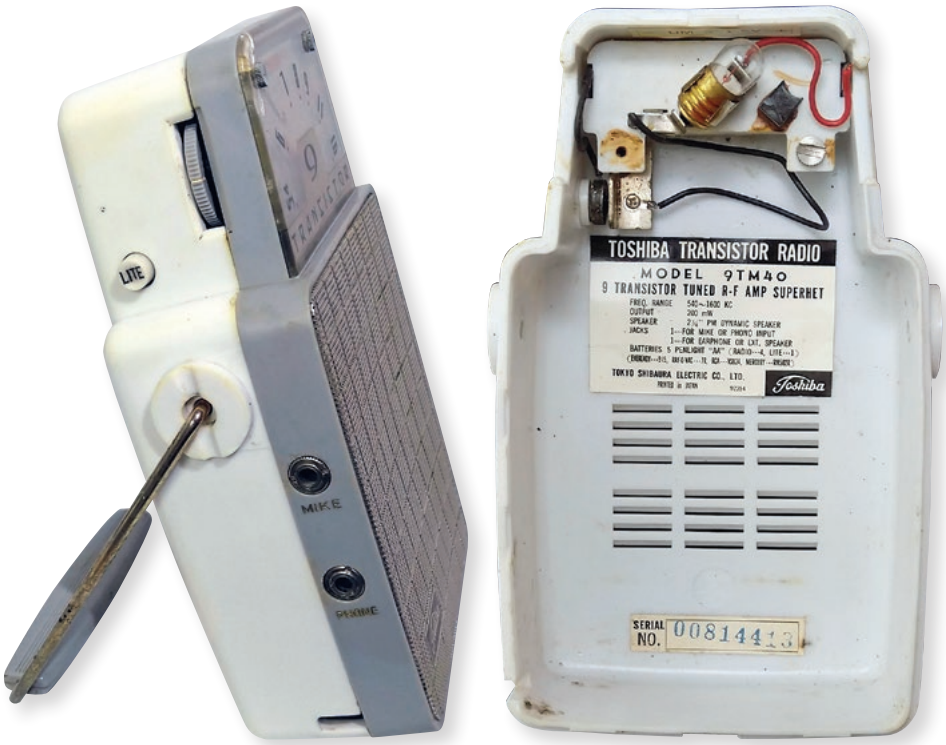
It's good without being outstanding. The surprises come from specifications not commonly examined.

Superhet radios are vulnerable to image interference. This happens when one station is tuned in, and another nearby station exists that's two times the IF up the band.

For example, 3WV in Horsham, Victoria, broadcasts on 594kHz. There's a Melbourne community station, 3KND, on 1503kHz. For a set with an IF of 455 kHz, we get 1504kHz (2 × 455kHz + 594kHz), just about 3KND's frequency. So it's possible to tune in 3WV and get 3KND instead, depending on their relative signal strengths!

Circuits tuned to the signal frequency improve image response, and most sets use a single signal-frequency tuned circuit – the antenna circuit. Such sets give an image rejection ratio in the 40-60dB range. That's good enough for most situations, but the extra tuned circuit of a tuned RF stage should improve image rejection.

The 9TM-40's 88dB Image Response Rejection Ratio (IRRR) at 600kHz is around 30dB better than radios with



On the side of the 9TM-40 is the knob for volume control and a switch labelled "LITE" which switches the on dial lamp shown at right. There is also a connector for a microphone (upper) and external speaker (lower).

no RF stage, putting it into the high-performance club.

Under my test conditions, and for the standard 50mW output, it needs around 110µV/m at 600kHz and 150µV/m at 1400kHz for signal-to-noise ratios (SNR) of 12dB and 16dB respectively. For 20db SNR, sensitivities were 175µV/m and 200µV/m. On air, it was able to pull in my reference 3WV over in Western Victoria with ease.

RF Bandwidth is ±1.85kHz at -3dB; at -60dB, it's ±29kHz. AGC action is acceptable; a 40dB increase at the input gave an output rise of just 6dB.

Audio response is 200Hz~7kHz from volume control to speaker; from the antenna to the speaker, it's 160~1800Hz.

Audio output is about 100mW at clipping, with 110mW out at 10% THD (total harmonic distortion). At 50mW, THD is around 5%; at 10mW, it's about 4%.

With a low battery voltage of 3V, it clips at 25mW, with 8% THD at 20mW output. There was notable crossover distortion, confirming the voltage-divider bias circuit's failure to apply correct bias at low battery voltages.

Special handling

If you are buying one of these sets, be sure to get photos of both battery compartments. The main battery (four AAs) is held in a case, easily replaced if corroded. The single AA for the dial lamp is held in a compartment inside the set that needs the back removed for access, and mine looked like it was the original from the factory. It was severely corroded. Some sellers may not even know of its existence.

Further reading

As with the 7TH-425, I found a SAMS Photofact online. These are excellent guides available at fair prices, but be alert to postage costs; postage can exceed the purchase price, depending on the supplier and postage service. Do be aware of occasional mistakes, and of their peculiar drawing layout and component numbering styles.

Conclusion

It would be nice to find a complete 9TM-40 with accessories, especially the small crystal microphone that came in the presentation case.

Toshiba's design studio continued with distinctive styling in following sets, such as the 6TP-309, 6TP-31 and 7TP-303. But I'm not too optimistic about finding them in a local second-hand shop. SC

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Allan Linton-Smith looks at an exciting speaker development from Europe: MEMS speakers

How many speakers can you fit on a 5 cent coin?

MEMS, or Micro Electrical-Mechanical Systems, represents a significant breakthrough in electronics technology.

We're looking here at the USound UT-P-2017 MEMS loudspeaker. Using integrated circuit (IC) fabrication and device packaging processes, an Austrian audio/semiconductor company, USound GmbH (www.usound.com) managed to pack a fully-functioning speaker into a device just 6.7 x 4.7 x 1.6mm – and weighing just 47mg.

If you're having difficulty converting the measurement to reality, look at this rectangle – ▭ – that's the actual size of this speaker!

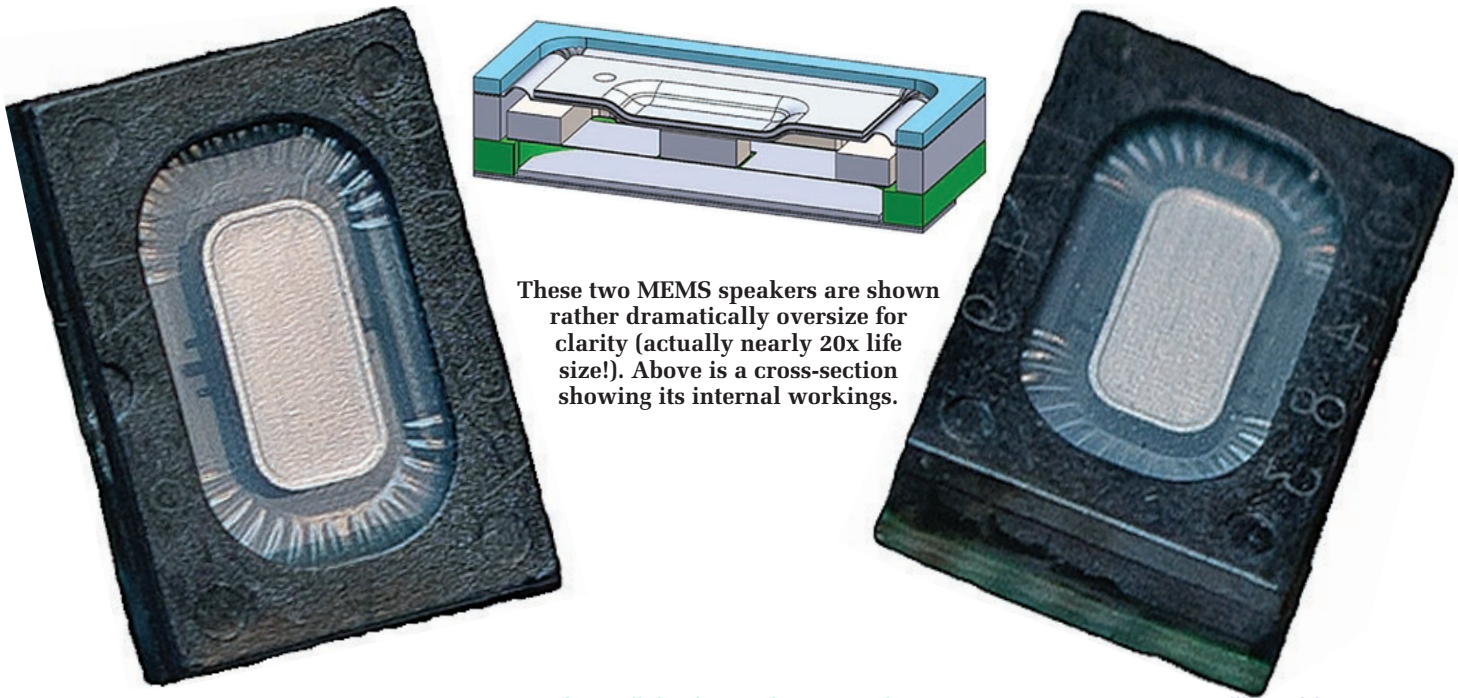
The manufacturer claims it is not only suitable for earwear, hearing aids, smartphones and the like but for much larger projects – such as a full-scale free field tweeter mounted in large hifi speakers!

The USound MEMS device

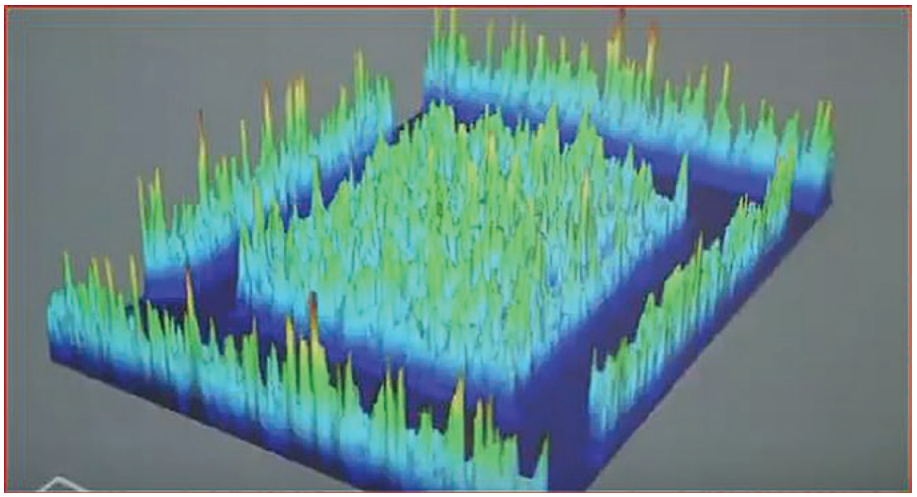
USound first brought this very-low-profile MEMS microspeaker to market towards the end of last year. It was initially targeted at wearables, headsets, embedded speakers and the like.

While this is described as a piezo tweeter, they were able to overcome the limitations of traditional piezo transducers, producing microspeakers with significantly improved sound pressure levels (SPLs) and low distortion as well. The UT-P-2017 offers a frequency range of 2kHz to 20kHz

Previous versions of piezo microspeakers available were not successful because of their limited excursion and lack of adequate bottom-end and midrange output.



These two MEMS speakers are shown rather dramatically oversize for clarity (actually nearly 20x life size!). Above is a cross-section showing its internal workings.



USound's MEMS speaker 3D doppler holograph from their development and testing phase. Note how the sound is emitted uniformly from the microspeaker.

One application suggested by the manufacturer is in "wearable" audio, such as these sunglasses. They have full-range stereo MEMS speakers plus a microphone built in. You can use them in place of earbuds for your smartphone! Prescription lenses are also available if you need them. They are available for around 300 Euros from USound (see website for details).

However, now they have successfully evolved with larger and thinner ceramics and the force of the ceramic element is high, enabling a cantilever to increase excursion and increase sound levels.

They are also easy to mount commercially because they can be soldered in place by reflow soldering techniques, which is how most miniature electronic SMD components are incorporated. They are in fact an SMD speaker!

Fortunately they can also be soldered to manually, but you have to have a steady hand and handle the device carefully according to the manufacturers datasheet: **www.usound.com/wp-content/uploads/2019/12/1912_Adap-UT-P-2017-Datasheet.pdf**

These little speakers can be made far more easily than conventional moving coil miniature speakers which require manual manufacturing steps. It has been estimated that MEMS speakers will require 1,000 times less manufacturing time to produce!

We obtained some of the USound MEMS speakers from DigiKey (part no 2000-1013-ND).

They were a bit expensive at about $AU21.50 each, including freight to Australia. The price has since come down a little (despite a falling Aussie dollar) and naturally, if you buy in any sort of quantity, there are good discounts.

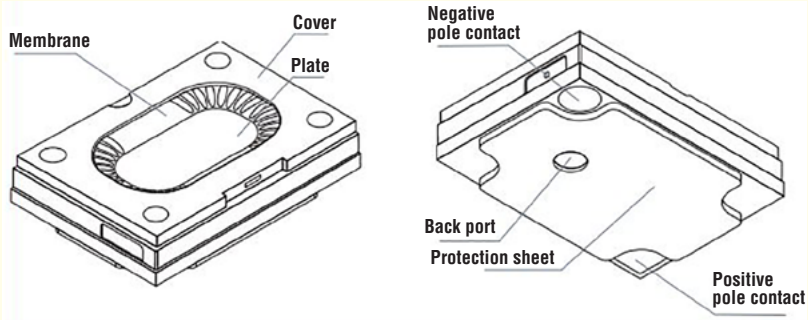
Incidentally, there is another model available from Digikey, the USound UT-P-2016 which is a full-range, in-ear speaker with a relatively flat 20Hz-9kHz (we hope to also look at this one soon).

SPECIFICATIONS: U SOUND UT-P-2017

PARAMETER	SPECIFICATION
Fundamental resonance	2.9kHz (15V pk-pk)
Q @ Fundamental resonance	0.7 (15V pk-pk)
Effective membrane surface	12mm²
VAS	40mm³
Front volume (inside speaker)	5.6mm³
Back volume (inside speaker)	20mm³
Capacitance (1kHz 15V_{pp})	40nF
Power consumption, 60dB white noise	27mW
Power consumption, 60dB pink noise	32mW
Max DC voltage	15V
Max AC voltage	15V pk-pk
Max frequency	40kHz
Overall dimensions, LxWxH	6.7 x 4.7 x 1.56mm
Total weight	47mg

The specifications show that the parameters are really tiny compared to larger, "normal" tweeters – and let's face it, ANY other tweeter is bigger than this one! Remarkably, the tiny size is really an advantage because the membrane can easily respond to more than 30kHz.

For a general description by the manufacturer go to: **www.youtube.com/watch?v=aAYrFVKW1XM**



The MEMS speaker is miniscule, measuring only 6.7x4.7 mm and weighing just 47 milligrams! Fortunately it can be soldered to connecting wires – but you have to have a steady hand and handle the device carefully.

MEMS impedance

Basically what we have here is a sort of electrostatic speaker, although in reality it is described as a "piezo silicon" device.

It acts like a capacitor and is very efficient; however, as with most of its big brothers, it requires a higher voltage input than dynamic speakers – but requires less current and therefore less power.

One drawback is that some amplifiers don't like capacititive loads, which may cause "ringing" or spurious oscillations.

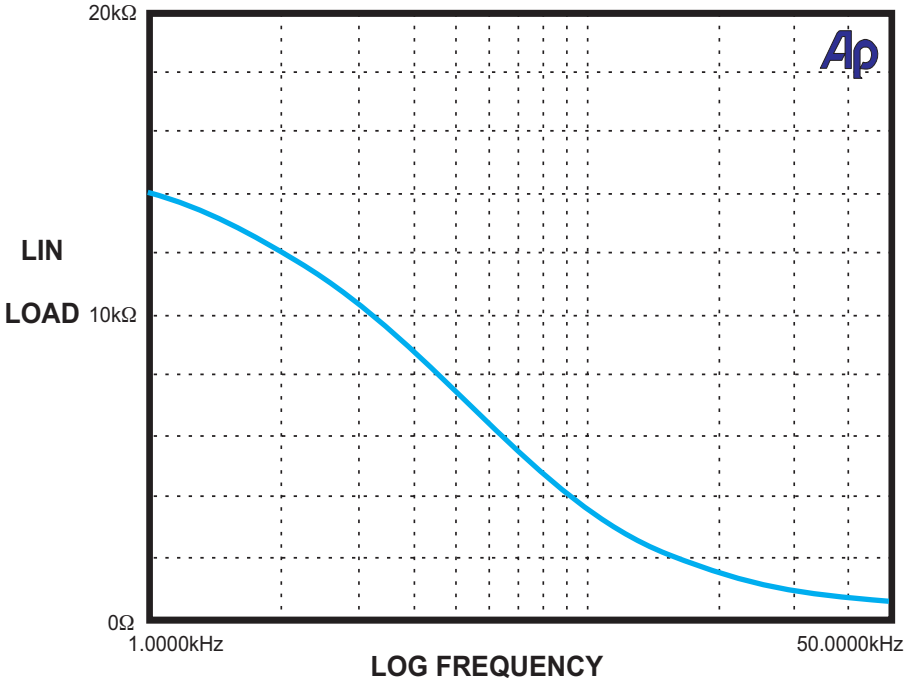


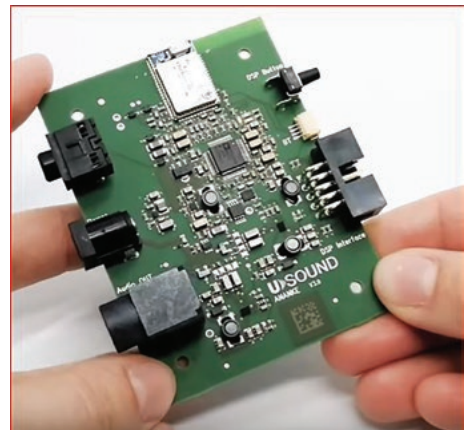
Fig.1: the impedance vs frequency curve shows a very high impedance across the range, only dropping under 1kΩ over 25kHz. This makes it suitable to be driven from just about any amplifier, including many preamplifiers or headphone amplifiers, but Class-D amplifiers are not recommended.

A circuit is described using an LM1875 power amplifier chip which is modified to cope with this speaker.

The nominal impedance is quoted as 161Ω – however, you can see from the impedance graph that this speaker has a smoothly declining impedance, typical of a capacitor, but at the same time it avoids impedance troughs and peaks which are usual with most other speakers. The result is better quality, smoother sound.

The impedance vs frequency curve from our test setup shows a very high impedance across the range of 1kHz to 50kHz – from 13.9kΩ down to 0.44kΩ. It only drops under 1kΩ over 26kHz.

This makes it suitable to be driven from just about any amplifier, including many preamplifiers or headphone amplifiers. However, we would be cautious with class-D amplifiers because of their heavy high frequency output (usually significant above 20kHz) which may overload the microspeaker because of its incredibly high frequency response which is significant – from 3kHz to an incredible 40kHz!



For future experimental work you can obtain a USound evaluation kit. Full details are included on their website. Also watch the whole thing on www.youtube.com/watch?v=9GInWhqHRFU

Power supply

For this speaker to function it requires a 15V supply (which may of course already be available in the power supply of an amplifier).

Bear in mind that 15V is the maximum allowed and the speaker will

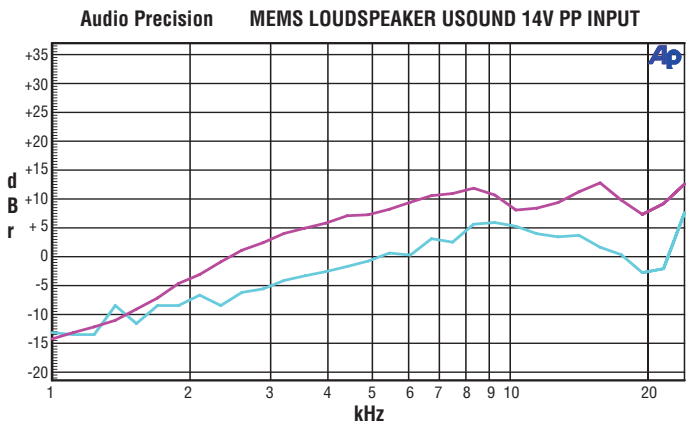


Fig.2: frequency response of the USound MEMS loudspeaker is quite smooth at its near-maximum of 14Vpp (4.95V RMS) and is close to the manufacturer's test data which was also taken at a nearfield distance of 3cm. The top trace (purple) was taken on the tweeter axis and the bottom trace (cyan) is 30° off axis. Zero dBr was set at 1Pa which represents a sound pressure level of 94dB, so the peak is an SPL of 106dB. The speaker had no problem in reproducing 102dB at 24kHz! The same circuit was used as for Fig.1 with the recommended DC bias of 15.0V.

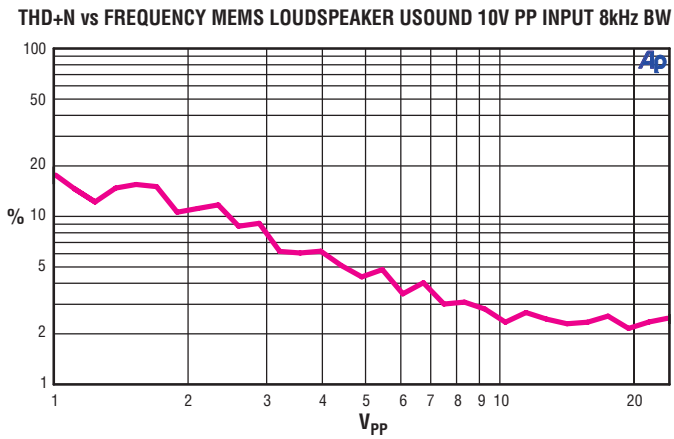


Fig.3: THD+N vs input (Volts$_{pk-pk}$). Distortion drops significantly as the voltage increases up to its rated maximum of 15V or 5.32V RMS. Note that the lowest distortion is achieved from approx 7-15V which is easily handled by most audio amplifiers. We used a bandwidth of 80kHz and a fixed frequency of 8kHz because this is a tweeter and the conventional 1kHz is not recommended. Also bear in mind that even our lab-grade Bruel and Kjaer mics contribute about 0.4% distortion to these measurements so it is pretty impressive!

A suggested bookshelf speaker arrangement developed by USound using MEMS microspeaker tweeters and conventional woofers. USound have a YouTube video for a blow-by-blow guide of how you can put them together. NOTE: As well as the conventional 8" woofer you will need 40 MEMS speakers to get the required volume! Full instructions are also available from their website, including recommended construction techniques, dimensions and recommended amplifiers and crossovers.

work quite happily at lower voltages, as long as the input peak-to-peak voltage does not exceed the DC voltage.

Lower voltages will naturally limit the power output and the sound pressure level.

Another option (which the manufacturer recommends) is a boost converter (see boost circuit diagram). USound operates from a 1.8-5.5V DC source and delivers a 15V DC output with 100mV ripple.

This IC is a tiny SMD suitable for in-ear applications but for a free field application, larger DC-DC converters or DC supplies within other amplifiers can be used to obtain the required power supply.

USound performance

One big advantage of a tiny item like this is that it allows a frequency response to a level only bats and dogs might be able to hear (getting some ideas are you?) because the membrane is so small and therefore can move very fast.

Also, because it is effectively a capacitor, its impedance has no significant peaks or troughs so it will be easy to drive.

It won't require a lot of signal and virtually any amplifier, even a preamplifier will be OK as long as it can deliver up to 5.3V RMS (15V peak-to-peak).

USound speaker practical applications

A hi-fi bookshelf speaker system was developed by USound using MEMS microspeaker tweeters and conventional 8-inch woofers.

Excellent instructions are available from their website including plans, recommended construction techniques, dimensions and recommended amplifiers and crossovers.

They even include detailed information to make the tweeter horn via 3D printing. They also describe a superb step by step guide to building this on YouTube: **www.youtube.com/watch?v=kx_JiYMPaZ8**

This speaker, also designed by USound, has 3x20 MEMS tweeters in a 360° arrangement for full "spaced out" sound. The woofer is a 2.5-in driver in a small box to provide the bass and lower midrange support. The effect is considered to be very unusual!

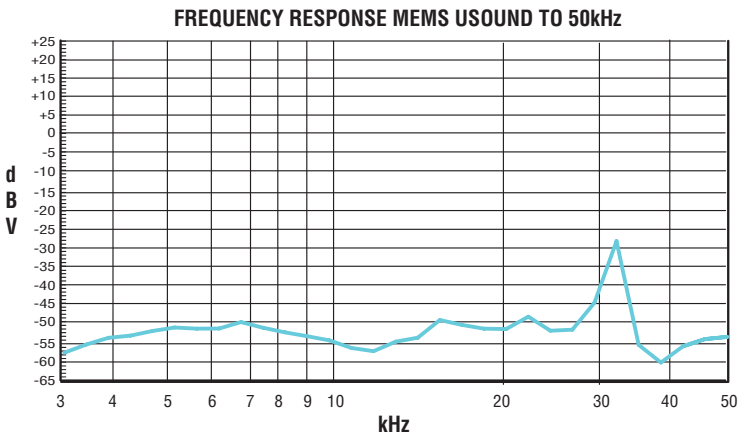


Fig.4: this THD+N vs frequency graph shows its response goes to an astounding 50kHz with a large peak at 32kHz, probably due to standing waves and/or resonance with the generator. It is remarkably flat to 50kHz and our B&K microphone responds to this frequency but is not calibrated above 40kHz. Note the manufacturer claims its response goes up to 80kHz and even bats and dogs probably won't hear it! Unfortunately we can't hear it or detect it either!

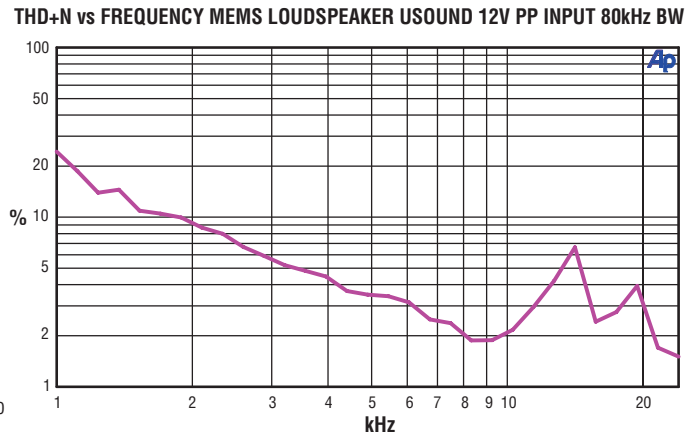
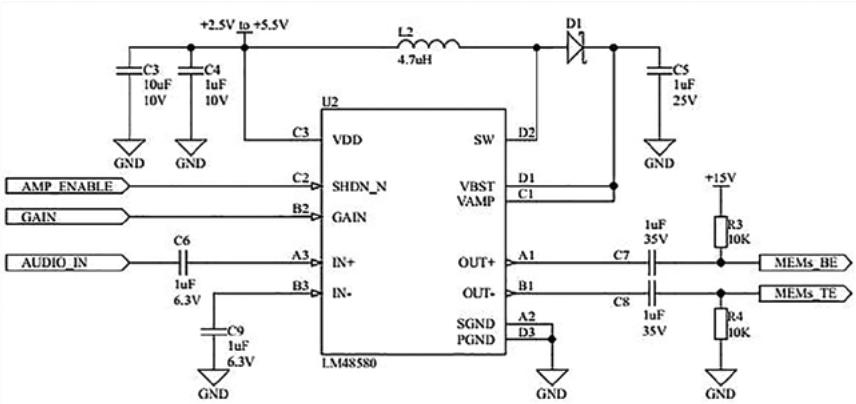
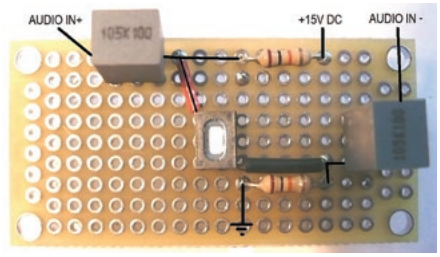


Fig.5: Total Harmonic Distortion plus noise (THD+N) vs frequency shows that our "mockup" results are as the manufacturer designed. It has a fairly low distortion in the 5-10kHz range and is very low at 20-24kHz. This speaker would use a high pass filter at 3kHz or higher to be in its "happy" range. Measurements were taken from our mocked up board and the Bruel & Kjaer microphone was mounted near field at 3cm from the speaker. The results are quite acceptable and the distortion levels are comparable to a full blown dynamic speaker.



The boost converter recommended by USound operates from a 1.8-5.5V dc source and delivers a 15V DC output with 100mV ripple. This IC is a tiny SMD type, suitable for earware, but for a free-field application there are probably easier ways to obtain the required voltage.



Our perforated board mock-up to allow us to evaluate the UT-P-2017 MEMS loudspeakers. We found that they performed very close to their published specifications.

We did "try out" the USound MEMS speakers but have not yet had time to re-create their built-up units. However, we may have a look at them in the future.

This stereo speaker system uses 20 microspeakers in each box in a vertical horn arrangement and presumably puts out significant sound.

There is another speaker system which requires 40 microspeakers in each box with a bigger woofer.

Another innovative speaker designed by USound has 20 MEMS tweeters in a thin metal tube which is angled slightly.

Three of these tubes surround a small woofer in a 360° arrangement for full spaced-out sound. The woofer is a 2.5-in driver in a small box to provide the bass & lower midrange support.

The effect is considered to be very unusual and spooky!

All sorts of innovations come to mind when you can have a thin tweeter and mount it on a flat surface and the obvious one is for earphones, earbuds and headphones. But there are many other novel uses and for this particular unit which is designed for free sound or open sound.

Virtually anywhere you have restricted space and power or you require close proximity sound is a good candidate.

Other applications

Because these microspeakers can be mounted on flat surfaces, they could find a ready market in computer tablets, laptops etc, vehicle dashboards and aero cockpits, instruments, calculators, books, talking magazines (SILICON CHIP?), supermarket shelf talkers, white goods and many similar applications.

Motor vehicle tweeters

Another likely market will be to solve an age-old problem in motor-vehicles.

Tweeters in cars are often "buried" – either in the dash, in doors, etc. Due to this, high frequency sound is often blocked by seats, front seat occupants, headrests and more.

So back seat passengers usually don't get quality audio.

But with flat MEMS tweeters, mounted, for example, above everyone's heads in the headlining, everyone could get to hear uninterrupted, full frequency sound! SC

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Recommendation for hot air rework station

I love this month's magazine (April 2020). I'm very interested in the PID controller for the reflow oven, which leads me to my first question. I am thinking of purchasing a new solder rework station. I want one with a standard iron plus hot air rework, but the dazzling array of stations available makes the choice very hard.

I don't want to buy one from eBay, especially a cheaper one as there are a few horror stories of unavailable parts or lack of electrical safety compliance. I have scanned the usual retailers including Jaycar and Altronics, but I am at an impasse. So, do you have any suggestions or recommendations for me? I am willing to spend up to $300, or maybe $400 to get the right features.

Also, will there be a kit for the PID controller?

Lastly, I have an infrared beam across the street entrance to my garage (things have been known to 'walk out' all on their own…). It works very well, but at odd times during the day, it goes off! I think I have tracked the problem to the outside beer fridge. I believe when the fridge compressor turns on or off, the ripple in the mains trips the beam and off it goes.

I have tried wrapping the power cable for the beam through a powdered iron core. I have also tried putting a similar core on the low-voltage side of the SMPS, but it still chimes when there is no one anywhere near the garage.

I thought about changing the power point the SMPS was fitted into, but the house uses a ring main for all the power points so that would be pointless. I cannot unplug the outside fridge; I have already unplugged everything else that I can think of. (D. S., Maryborough, Qld)

● We are happy with the 'cheapie' hot air rework station we have here, but take your point about electrical safety (or lack thereof) in eBay purchases. While we prefer separate tools, we can't see anything wrong with the Jaycar Cat TS1648 two-in-one system, which is within your budget.

You could look at premium brands like Hakko and Thermaltronics (you can't go wrong with either), but their equivalent station will probably be over your $400 budget.

We don't think that anyone will make a kit for the toaster oven PID controller, given its extensive use of SMD components.

We sell the PCBs, programmed micro and thermocouple interface module on our website (see **siliconchip.com.au/Shop/8/5404**). The other parts should all be available from Digi-Key and Mouser, or Jaycar/Altronics for some parts (like the case).

We suggest that you try powering the infrared beam trigger device from a bench supply for a few days to see if that fixes the problem, due to superior voltage regulation. If so, you may need a better regulated SMPS or a linear post-regulator; or perhaps an RC/LC filter on its output with a large value capacitor.

If it still trips even when running from a bench supply, likely the beam trigger device is picking up EMI radiated by the power lines due to the current spikes generated by the fridge compressor. In that case, you may have to try shielding it in a metal box, ideally steel (with a hole for the beam to go through, obviously!).

Replacing soldering station controller

We recently bought an old Weller EC1001 48W soldering station with soldering pencil model EC1201A. I believe that it is quite an old model, but it was working fine.

When it arrived, I noticed a rattle inside the base unit. I pulled it apart to find the printed circuit board was floating around inside the case.

Unfortunately, when I went to click it back into place under the two plastic supporting clips, the board cracked. Worse still, this board appears to be made out of a ceramic material, and the board has several resistors printed directly on to it, along with the chip, which is under an epoxy blob.

I tried to repair the board, but without success. Have you published a circuit that I can use to replace this board? The soldering pencil is a 24V AC unit, and has (I believe) a thermocouple built into it; I have no idea which type, though. The station only has a pot to set the temperature over the range of 200-450°C, with no display other than an LED which flashes while the iron is heating.

The power is fed to the soldering pencil via what I assume is a Triac. Are you able to help me? (P. W., Pukekohe, NZ)

● We found extensive information on building your own controller for a soldering station on this website: **www.zl2pd.com/SolderingStation.html**

That describes a soldering pencil which uses a PTC thermistor for sensing the tip temperature. If yours does indeed use a thermocouple, you will need a way to convert its output to a usable voltage.

We published a High-Temperature Thermometer/Thermostat design in the May 2012 issue (**siliconchip.com.au/Article/674**) which converts the thermocouple temperature to a voltage and displays the temperature on a panel meter.

Bookshelf speaker inductor values are off

I am concerned about the coils used in the passive crossovers for the Bookshelf Speaker System (January-March 2020; **siliconchip.com.au/Series/341**). The article calls for 900µH and 390µH coils, and specifies full roll of 0.8mm ECW (Altronics W0407) and a full roll of 1mm ECW (Altronics W0408) respectively.

I purchased the required coils, and I measured the inductance with my multimeter. In the case of the two 900µH coils, I measured 950µH and 942µH. This is good as the article

states the design calls for 1mH coils, but 900µH is sufficient.

However, in the case of the four 390µH coils, I measured 319µH, 328µH, 330µH and 335µH. The article does not give any indication of an acceptable range of inductance. Are these values satisfactory? Or should I increase the number of turns to build the inductance up to about 390µH? I reckon there would be enough room on the bobbins to do this. (M. J., Cootamundra, NSW)

● We checked with the author, Phil Prosser, and he replied: 330µH is lower than I would like. Variations of say ±10% (355-430µH) are acceptable, provided both inductors are about the same. The crossover is a Chebychev alignment, and the inductors in the high and low pass 'correlate' across the two filters.

So an error that is similar in both simply shifts the crossover frequency slightly. But values of 330µH would push the crossover frequency up from 3.2kHz to around 3.6kHz; a fairly significant error.

I bought another coil from Altronics and measured it at 366µH. That was with the wires 'wrapped back' as originally supplied; when Altronics package them, they hook the wire over on itself in a way that results in a reverse turn. This reduces the inductance a bit, by probably 6-8µH. I unwrapped this folded-back turn and added one more turn, and the inductor then measured 390µH.

Taking 10 turns off this reduces the inductance to 330µH. So I think that you should add 10 turns of 1mm wire (solid or stranded will both work fine) to each. The inductor values will then be very close to correct.

Charging lead crystal batteries

Have you ever published an article about lead crystal batteries? The ability to fully discharge without damage to the battery is quite handy. Can any of your battery chargers be modified to charge one properly? Thank you for a great/useful magazine publication! (Peter, via email)

● No, we haven't described this type of battery, but our Universal Battery Charge Controller (December 2019; siliconchip.com.au/Article/12159) could be used to charge them as it has adjustable settings. The charging characteristics for this type of battery are shown in the accompanying graphs at the bottom of this page.

Finding pin 1 marking on SMD ICs

I've started building your 12/24V Universal Battery Charge Controller from the December 2019 issue. However, look as I may, I can see no indication dot for pin 1 on the Si8751 IC. There is some very faint printing on the top, but it is unreadable. Will it damage the chip if I put it in the wrong way, as trial and error seem the only option? (T. O. L., Ngaruawahia, NZ)

● There is a high likelihood of damage if power is applied to the circuit with any IC connected with an incorrect orientation. So you really need to find the pin 1 marker.

If there is no dot on top of the package, there will be a bevelled edge (as if the edge has been cut off diagonally) along the same edge as pin 1. You can also find pin 1 if you can read the label on top of the chip. In this case, with the writing orientated so you can read it, pin 1 is at lower left (see the Si8751 data sheet for more details). Other ICs may use a different labelling scheme.

The writing is often indistinct, but it can be made visible by shining a bright light (eg, sunlight) at a steep angle across the face of the chip. You may need to experiment with its orientation until you can read the label.

Using Charge Controller with a solar panel

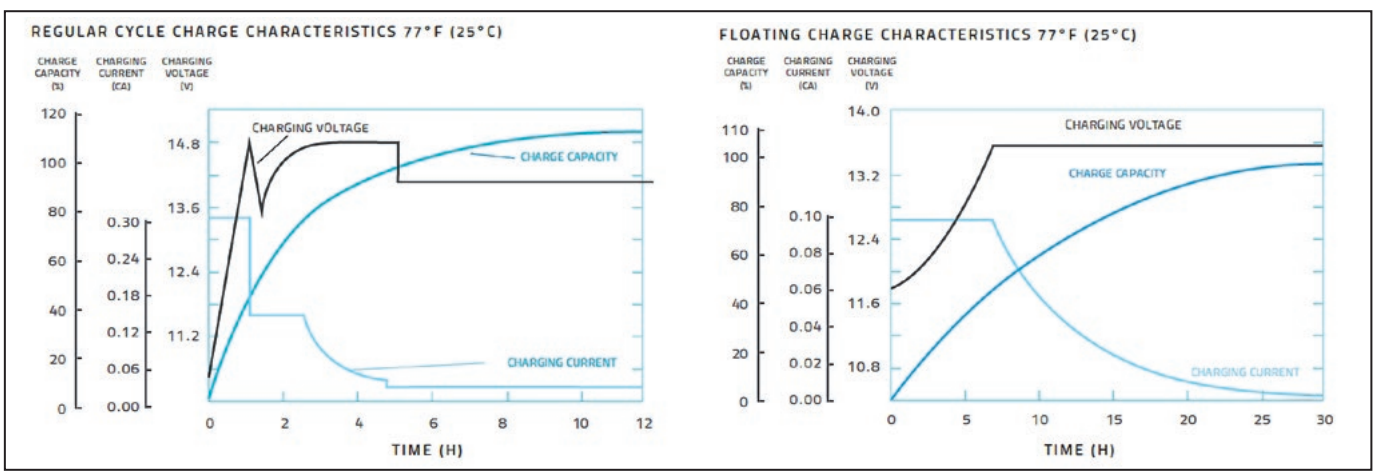
I read with interest your "Clever controller for a dumb battery charger" in the December 2019 issue. It certainly looks like a handy project, and I will definitely have a shot at building it, but I have one question. Is it possible to power the controller from a solar panel instead of a battery charger? (S. L., Walcha, NSW)

● You could power the Charge Controller from a 12V solar panel, but charging would be quite variable depending on the solar panel output. The output from a solar panel depends on the sun and the loading on the output, while the 'dumb' battery charger it is designed to work with is a fixed (if pulsating) DC voltage source.

For charging a battery from a solar panel, we recommend you instead use an MPPT Solar Battery Charger, for example, our design from the February & March 2016 issues (siliconchip.com.au/Series/296).

Using Charge Controller with $LiFePO_4$ battery

I have a question regarding the Universal Battery Charge Controller from December 2019. I would like to use it



Charging characteristics for lead crystal batteries

to charge a set of four 1.6Ah $LiFePO_4$ cells (ie, a ~12V pack). The only problem I can imagine is to do with the situation when input power is lost due to a blackout or other unforeseen situation.

$LiFePO_4$ cells have a very flat discharge curve, with a rapid drop in terminal voltage once they are exhausted. It doesn't take much to discharge them below 3V and reach the critical level of 2.5V/cell where damage starts to occur.

The article says that once power is lost, the battery supplies the hold relay for at least another two hours. Even though the battery might only have to supply about 50mA in this scenario, if it was fully discharged when connected to the charger and input power was lost soon after, that might be enough to discharge and damage the battery pack.

So is there a way to change the software to drastically reduce the time the hold relay is energised? Maybe around 5-10 minutes? I'm OK with modifying the code and reprogramming the PIC if I know what lines to alter. (M. H., Moonee Beach, NSW)

● We have slightly modified the code to change the way that the HOUR2 and HOUR3 counter values (at line 366) work. Using a value of 10 now gives a 10-minute timeout, and that has been achieved by changing the decrement of the HOUR2 value to be once per minute, rather than once per hour. The changed code for this is at line 1812. You can change the line 366 value to the minutes required.

The modified source code is available for download from the Silicon Chip website.

Diode Curve Plotter resistor value

Regarding the Multi Diode Curve Plotter (March 2019; **siliconchip.com.au/Article/11447**), I am a bit confused by the 12kΩ resistor. Or is it a 13kΩ resistor? The PCB silkscreen indicates 12kΩ, but the article says 13kΩ. Which is correct?

Regarding the Isolating High Voltage Probe for Oscilloscopes (January 2015; **siliconchip.com.au/Article/8244**), it uses four 100nF multilayer ceramic capacitors. I have some of these capacitors and checked their values. I found them to be between 82-84nF. Will these be OK or should I obtain some with higher values? (W. F., Atherton, Qld)

● Concerning the Multi Diode Curve Plotter, the value of that resistor is discussed at the bottom of page 64. The value of this resistor determines the inductor current and thus the maximum test voltage, so there is a degree of user discretion here. We suggest you use 12kΩ, but if you find the test voltage is not high enough, it can be changed to 13kΩ.

On the other hand, if you find that your power supply (eg, USB charger) cannot handle the required current, it can be reduced to 11kΩ, with the proviso that the maximum test voltage may be reduced.

To answer your second question, those readings are within the typical 20% tolerance for a high-value ceramic capacitor (some have a 10% tolerance, but 20% is probably more common). We therefore do not consider it to be a problem. Part of the reason for choosing 100nF for bypass capacitors is that this is 'more than enough', so some variation in actual capacitance should not cause problems.

Replacement for ST-4 DIACs

I am trying to repair a geriatric speed controller for my local bakery pastry roller. The roller uses a DC motor which has both the wound field coils and the armature voltages varied by way of an SCR-based speed controller. I have replaced both the BT151-500 SCRs and all the blown diodes and burnt resistors etc.

The problem is that it uses ST-4 DIACs to trigger the SCRs, and from the limited amount of information I can find on this device, it has a breakover voltage of about 7V. That is a lot lower than the DB2/3/4 series of DIACs, which are rated at about 30V.

Are you aware of any possible substitute for the ST-4? The motor is OK after a good overhaul, and a new set of brushes and bearings etc. (P. C., Woodcroft, SA)

● The ST-4 has an asymmetrical trigger voltage that is designed to reduce the snap-on effect of RC time-constant driven mains phase control circuits. For more information on this, see: **siliconchip.com.au/link/ab11**

You should be able to use the 30V DIAC instead. The only effect it will have is that the snap-on effect will be present and that the full waveform (for full speed) will not be provided. This is because the ST-4 (7V) DIAC will allow the mains waveform to drive the motor starting at about 2.5° from the zero-crossing point, while the 30V DIAC will start the waveform at around 11° from the zero crossing.

The resulting lower maximum RMS motor drive voltage would probably not have a noticeable effect on the motor speed.

Anti-Fouling transducer drive voltage

I'm building your Ultrasonic Anti-Fouling system but have run into a few problems. I measured the output voltage with the transducer disconnected and I get a reading below 200V – I was expecting around 250V. With the transducer connected, I can measure around 250V with output frequencies around 21kHz and 42kHz. At the other frequencies, the output collapses to 75V maximum.

Is this normal behaviour, or do I have a problem with my unit? (H. L., Papendrecht, The Netherlands)

● The voltages you are measuring are to be expected. The transducer acts as a capacitor to filter the square wave drive from the transformer. So the 250VAC reading is correct when the transducer is connected, but this voltage will vary with frequency due to the impedance of the transducer changing at resonance.

Transformer for CLASSiC-D amplifier

I recently purchased a kit to build your CLASSiC-D High Power Class-D Amplifier from Jaycar (Cat KC5514). I bought the KC5517 power supply kit as well. This requires a centre-tapped transformer with two 40V windings and two 15V windings. Jaycar has since discontinued this product, and I am unable to find another similar transformer. Do you know where I can get this transformer? (C. R., Canterbury, Vic)

● Neither the CLASSiC-D amplifier (November & December 2012; **siliconchip.com.au/Series/17**) nor its matching speaker protector require the ±15V DC rails which are derived from the 15V transformer secondaries. These are only required if you need to power a preamplifier or other similar device within the same amplifier chassis.

Assuming you just need to run the

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PRE-PROGRAMMED MICROS

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$10 MICROS

ATtiny816	ATtiny816 Development/Breakout Board (Jan19)
PIC12F202-E/OT	Ultrabrite LED Driver (with free TC6502P095VCT IC, Sept19)
PIC12F617-I/P	Temperature Switch Mk2 (June18), Recurring Event Reminder (Jul18) Door Alarm (Aug18), Steam Whistle (Sept18), White Noise (Sept18) Trailing Edge Dimmer (Feb19), Steering Wheel to IR Adaptor (Jun19) Car Radio Dimmer Adaptor (Aug19)
PIC12F675-E/P	Courtesy LED Light Delay (Oct14), Fan Speed Controller (Jan18)
PIC12F675-I/P	Driveway Monitor Receiver (July15), Hotel Safe Alarm (Jun16) 50A Battery Charger Controller (Nov16), Kelvin the Cricket (Oct17) Motor Speed Controller (Mar18), Heater Controller (Apr18) Useless Box IC3 (Dec18)
PIC12F675-I/SN	Tiny LED Xmas Tree (Nov19)
PIC16F1455-I/P	Microbridge and BackPack V2 / V3 (May17 / Aug19) USB Flexitimer (June18), Digital Interface Module (Nov18) GPS Speedo/Clock/Volume Control (Jun19)
PIC16F1459-I/P	Five-Way LCD Panel Meter / USB Display (Nov19)
PIC16F1507-I/P	Wideband Oxygen Sensor (Jun-Jul12)
PIC16F88-E/P	Auto Headlight Controller (Oct13), Motor Speed Controller (Feb14) Automotive Sensor Modifier (Dec16)
PIC16F88-I/P	Cyclic Pump Timer (Sep16), 60V DC Motor Speed Controller (Jan17) Pool Lap Counter (Mar17), Rapidbrake (Jul17) Deluxe Frequency Switch (May18), Useless Box IC1 (Dec18) Remote-controlled Preamp with Tone Control (Mar19) UHF Repeater (May19), Six Input Audio Selector (Sept19) Universal Battery Charge Controller (Dec19)
PIC16LF88-I/P	Garbage Reminder (Jan13), Bellbird (Dec13) GPS-synchronised Analog Clock Driver (Feb17)

$15 MICROS

ATmega328P	RF Signal Generator (Jun19)
PIC16F1459-I/SO	Four-Channel DC Fan & Pump Controller (Dec18)
PIC16F877A-I/P	6-Digit GPS Clock (May09), 16-bit Digital Pot (Jul10), Semtest (Feb12)
PIC18F2550-I/SP	Battery Capacity Meter (Jun09), Intelligent 12V Fan Controller (Jul10)
PIC32MM0256GPM028-I/SS	Super Digital Sound Effects (Aug18)
PIC32MX170F256D-501P/T	44-pin Micromite Mk2 (Aug14), 4DoF Simulation Seat (Sept19)
PIC32MX170F256B-50I/SP	Micromite LCD BackPack V1-V3 (Feb16 / May17 / Aug19) GPS Boat Computer (Apr16), Micromite Super Clock (Jul16) Touchscreen Voltage / Current Ref. (Oct16), Deluxe eFuse (Aug17) Micromite DDS for IF Alignment (Sept17), Tariff Clock (Jul18) GPS-Synched Frequency Reference (Nov18), Air Quality Monitor (Feb20)
PIC32MX270F256B-50I/SP	ASCII Video Terminal (Jul14), USB M&K Adaptor (Feb19)
PIC32MX795F512H-80I/PT	Maximite (Mar11), miniMaximite (Nov11), Colour Maximite (Sept12), Touchscreen Audio Recorder (Jun14)

$20 MICROS

dsPIC33FJ128GP306-I/PT	CLASSiC DAC (Feb13)
dsPIC33FJ128GP802-I/SP	Digital Audio Delay (Dec11), Quizzical (Oct11) Ultra-LD Preamp (Nov11), LED Musicolour (Oct12)
PIC32MX470F512H-I/PT	Stereo Echo/Reverb (Feb 14), Digital Effects Unit (Oct14)
PIC32MX470F512H-120/PT	Micromite Explore 64 (Aug 16), Micromite Plus (Nov16)
PIC32MX470F512L-120/PT	Micromite Explore 100 (Sept16)

$30 MICROS

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PIC32MZ2048EFH064-I/PT	DSP Crossover/Equaliser (May19), Low-Distortion DDS (Feb20) DIY Reflow Oven Controller (Apr20)

SPECIALISED COMPONENTS, HARD-TO-GET BITS, ETC

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VARIOUS MODULES & PARTS

- **MAX038 function generator IC (H-Field Transanalyser, May20)** — **$25.00**
- **MC1496P double-balanced mixer (H-Field Transanalyser, May20)** — **$2.50**
- AD8495 thermocouple interface (DIY Reflow Oven Controller, Apr20) — **$10.00**
- WS2812 8x8 RGB LED matrix module (El Cheapo Modules, Jan20) — **$15.00**
- Si8751AB 2.5kV isolated Mosfet driver IC (Charge Controller, Dec19) — **$5.00**
- I/O expander modules (Nov19): PCA9685 – **$6.00** ¦ PCF8574 – **$3.00** ¦ MCP23017 – **$3.00**
- SMD 1206 LEDs, packets of 10 unless stated otherwise (Tiny LED Xmas Tree, Nov19): yellow – **$0.70** ¦ amber – **$0.70** ¦ blue – **$0.70** ¦ cyan – **$1.00** ¦ pink (1 only) – **$0.20**
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- 23LCV1024-I/P SRAM & MCP73831T (UHF Repeater, May19) — **$11.50**
- MCP1700 3.3V LDO regulator (suitable for USB M&K Adapator, Feb19) — **$1.50**
- LM4865MX amplifier & LF50CV regulator (Tinnitus/Insomnia Killer, Nov18) — **$10.00**
- 2.8-inch touchscreen LCD module with SD card socket (Tide Clock, Jul18) — **$22.50**
- ESP-01 WiFi Module (El Cheapo Modules, Apr18) — **$5.00**
- WiFi Antennas with U.FL/IPX connectors (Water Tank Level Meter with WiFi, Feb18): 5dBi – **$12.50** ¦ 2dBi (omnidirectional) – **$10.00**
- NRF24L01+PA+NA transceiver, SNA connector & antenna (El Cheapo, Jan18) — **$5.00**
- WeMos D1 Arduino-compatible boards with WiFi (Sep17, Feb18): ThingSpeak data logger – **$10.00** ¦ D1 R2 with external antenna socket – **$15.00**
- ERA-2SM+ MMIC & ADCH-80A+ choke (6GHz+ Frequency Counter, Oct17) — **$15.00**
- VS1053 Geeetech Arduino MP3 shield (Arduino Music Player, Jul17) — **$20.00**
- 1nF 1% MKP (5mm) or ceramic capacitor (LC Meter, Jun18) — **$2.50**
- MAX7219 red LED controller boards (El Cheapo Modules, Jun17): 8x8 SMD/DIP matrix display – **$5.00** ¦ 8-digit 7-segment display – **$7.50**
- AD9833 DDS modules (Apr17): gain control (DDS Signal Generator) – **$25.00** ¦ no gain control – **$15.00**
- CP2102 USB-UART bridge — **$5.00**
- microSD card adaptor (El Cheapo Modules, Jan17) — **$2.50**
- DS3231 real-time clock module with mounting hardware (El Cheapo, Oct16) — **$5.00**

CAR ALTIMETER (BACKPACK V2 / V3 KIT) *(MAY 20)*

- BMP180 temperature/pressure sensor (Cat SC4343) — **$5.00**
- DHT22 temperature/humidity sensor (Cat SC4150) — **$7.50**

DCC BASE STATION HARD-TO-GET PARTS (CAT SC5260) *(JAN 20)*

- Two BTN8962TA motor driver ICs & one 6N137 opto-isolator — **$30.00**

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- CA3089E IC, DIP-16 (Cat SC5164) — **$3.00**
- MC1310P IC, DIP-14 (Cat SC4683) — **$5.00**
- 110mm telescopic antenna (Cat SC5163) — **$7.50**
- Neosid M99-073-96 K3 assembly pack **(two required)** (Cat SC5205) — **$6.00ec**

TINY LED XMAS TREE COMPLETE KIT (Cat SC5180) *(NOV 19)*

Includes PCB, micro, CR2032 holder (**no cell**), 12 red, green and white LEDs plus four extra 100Ω resistors and all other parts. Green, red or white PCBs are available. — **$14.00**

MICROMITE EXPLORE-28 (CAT SC5121) *(SEPT 19)*

- **Complete kit –** includes PCB plus programmed micros and all onboard parts — **$30.00**
- **Programmed micros –** PIC32MX170F256B-50I/SO + PIC16F1455-I/SL — **$20.00**

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KIT – includes PCB, programmed micros, 3.5in touchscreen LCD, laser-cut UB3 lid, mounting hardware, SMD Mosfets for PWM backlight control and all other **mandatory** on-board parts — **$75.00**

Separate/Optional Components:

- 3.5-inch TFT LCD touchscreen (Cat SC5062) — **$30.00**
- DHT22 temp/humidity sensor (Cat SC4150) — **$7.50**
- BMP180 (Cat SC4343) **OR** BMP280 (Cat SC4595) temp/pressure sensor — **$5.00**
- BME280 temperature/pressure/humidity sensor (Cat SC4608) — **$10.00**
- DS3231 real-time clock SOIC-16 IC (Cat SC5103) — **$3.00**
- 23LC1024 1MB RAM (SOIC-8) (Cat SC5104) — **$5.00**
- AT25SF041 512KB flash (SOIC-8) (Cat SC5105) — **$1.50**
- 10µF 16V X7R through-hole capacitor (Cat SC5106) — **$2.00**

GPS SPEEDO/CLOCK/VOLUME CONTROL *(JUN 19)*

- 1.3-inch 128x64 SSD1306-based blue OLED display module (Cat SC5026) — **$15.00**
- MCP4251-502E/P dual-digital potentiometer (Cat SC5052) — **$3.00**

TOUCH & IR REMOTE CONTROL DIMMER *(FEB 19)*

- Q1/Q2 Mosfets (SIHB15N60E) and two 4.7MΩ 3.5kV resistors (Cat SC4861) — **$20.00**
- IRD1 (TSOP4136) and fresnel lens (IML0688) (Cat SC4862) — **$10.00**

MOTION SENSING SWITCH (SMD VERSION) *(FEB 19)*

- Kit (includes PCB and all parts; **no extension cable**) (Cat SC4851) — **$10.00**
- SW-18010P vibration sensor (S1) (Cat SC4852) — **$1.00**

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60V 40A DC MOTOR SPEED CON. MAIN PCB	JAN17	11112161	$10.00
↳ MOSFET PCB	JAN17	11112162	$12.50
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DELUXE EFUSE	AUG17	18106171	$15.00
↳ UB1 LID	AUG17	SC4316	$5.00
VALVE RADIO MAINS SUPPLY (INC. PANELS)	AUG17	18108171-4	$25.00
3-WAY ADJUSTABLE ACTIVE CROSSOVER	SEP17	01108171	$20.00
↳ FRONT/REAR PANELS	SEP17	01108172/3	$20.00
↳ CASE PIECES (BLACK)	SEP17	SC4403	$10.00
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↳ CASE PIECES (CLEAR)	OCT17	SC4444	$15.00
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PROPORTIONAL FAN SPEED CONTROLLER	JAN18	05111171	$2.50
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↳ CASE PIECES (CLEAR)	JAN19	SC4849	$.00
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↳ EXTENSION PCB	FEB19	10111193	$10.00
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↳ PUSHBUTTON PCB	MAR19	01111113	$5.00
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↳ UB3 LID (MATTE BLACK)	MAR19	SC4927	$5.00
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↳ COIL PCB	APR19	19111181	$5.00
↳ PIXEL PCB (16 PIXELS)	APR19	19111182	$5.00
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↳ DAC PCB	MAY19	01106192	$7.50
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↳ CASE PIECES & DIAL	NOV19	SC5166	$25.00
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↳ ACRYLIC BEZEL (BLACK)	NOV19	SC5167	$2.50
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TUNEABLE HF PREAMPLIFIER	JAN20	06110191	$2.50
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7-BAND MONO EQUALISER	APR20	01104201	$7.50
↳ STEREO EQUALISER	APR20	01104202	$7.50
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NEW PCBs			
H-FIELD TRANSANALYSER	**MAY20**	**06102201**	**$10.00**
CAR ALTIMETER	**MAY20**	**05105201**	**$5.00**

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amplifiers and speaker protector, you could use a 40-0-40 toroidal transformer such as from RS Online (300VA, Cat 117-6065; siliconchip.com.au/link/aaxr) or element14 (250VA, Cat 9530835; https://au.element14.com/9530835). If you do need the two 15V AC secondaries, it's easiest to simply add another small (~30VA) 15-0-15 toroidal transformer and wire the primaries up in parallel.

If you aren't fussed about making the maximum possible power from the amplifier, you could instead use Altronics Cat M5535C (siliconchip.com.au/link/aaxs). This is a 300VA toroidal transformer with two 35V AC secondary windings and two 15V windings. That will give you slightly lower supply rail voltages than the specified transformer, but it should still be good for substantial output power from the CLASSiC-D modules.

Audio Switcher LEDs are too dim

I recently built the 3-Input Stereo Audio Switcher (January 2012; siliconchip.com.au/Article/821), and the LEDs do not light up; I used Altronics S1177 switches. The relays work, and the 5V supply is OK, but when the switch is pressed I get only 0.75V across the LED (red probe to "A" and black probe to cathode). This works out to about 2.3mA through the LED.

Should the 1.8kΩ series resistors be 180Ω, giving approximately 27mA current flow for the LED? I checked the Notes and Errata section on your website but found no mention of this situation. (P. S., Mount Pleasant, SA)

● You could try a smaller resistor value, but 180Ω is probably too low. Somewhere between 470Ω and 1kΩ should make the LEDs brighter. The 1.8kΩ resistors we used provided adequate LED brightness on our prototype, and we haven't heard from anyone else that the LEDs are too dim.

When we checked other similar switches in the past, we found that they all lit up at a quite reasonable brightness with just one or two milliamps, regardless of LED colour – we tested red, green and blue.

Driving alphanumeric LCD from a PICAXE

Has there been a SILICON CHIP project in the past that demonstrates how to connect and program a PICAXE controller to drive a 16 x 2 LCD module? (P. H., Gunnedah, NSW)

● We published a Circuit Notebook entry which describes how to do that on page 64 of the November 2006 issue (PICAXE to LCD interface; siliconchip.com.au/Article/2808).

Finding VHF Masthead Preamplifier

Many years back, I bought and built a kit (DSE K3226) for your VHF Weather Satellite Receiver project (December 2003; siliconchip.com.au/Article/3854). But the kit seemed to be lacking the masthead preamplifier for it, and I was unable to get it up and running.

I have had some success running the freeware programs SDRSharp and WXtoImg with a TV dongle to receive images, but am having difficulties. I would like to use the dedicated receiver, but cannot since I do not have the masthead preamp. Was that supposed to come with the kit? If not, is it still possible to purchase the preamp?

Also, would it be possible to make up a 'phantom' power supply to run it off the TV dongle? And finally, since there are now three NOAA weather satellites, is it feasible to modify the original circuit to include the extra tuning parts and switch for all three? (W. S., Narangba, Qld)

● The VHF Masthead Preamp and Antenna were described in the January 2004 issue (siliconchip.com.au/Article/3326). As a result, the preamp was not regarded as part of the Receiver, and the kit suppliers sold it as a separate small kit.

The PCB for the Masthead Preamp (06101041) is no longer available, but we do have a PDF file that you can download from our website, which contains the pattern for both sides. The PCB is very small, so you may be able to etch one yourself.

It would be possible to run the Masthead Preamp via a 'phantom' power supply fed up the cable from your receiver, but you'll probably need a small adaptor to allow this to be done. The required adaptor is quite simple: a series capacitor of 10nF or so (to block the DC from the Receiver input), and a shunt inductor (RF choke) in parallel to feed in the DC from a suitable power supply.

Yes, it is quite feasible to change the tuning selector switch S2 to one with three positions and connect a third 50kΩ 10-turn trimpot in exactly the same way as VR4 and VR5, to allow a third satellite to be tuned in.

PVR damaged TV over HDMI connection

We have a fairly elderly Kogan TV with, until recently, a Topfield PVR connected to one of the three HDMI inputs. The other two HDMI inputs are connected to an Apple TV and a Telstra TV1. The audio is connected with an optical cable to a separate 5.1 amplifier. This arrangement has been in place for years and has chugged along with no problems.

A couple of months ago, when watching live TV via the Topfield (as distinct from something recorded to the hard disk), the picture would suddenly freeze to a very noisy still frame, and the audio would be deafening white noise. At this point, none of the controls on the TV or the remote worked. The only solution was to switch off the power to the TV.

When power was restored, the TV would come up as usual. This would happen every couple of weeks. Removing power from the PVR did not affect the fault once it occurred.

As time went on it became more frequent, then on switch-on, the PVR began announcing that it was checking the HDD. Then the HDD disappeared, and recording was not possible. I did the usual tests, swapping to another HDMI input, swapping cables etc, to no avail.

I decided that since the unit ran quite hot (it has no fan) that faulty electrolytic capacitors could be the problem. I replaced about 20 capacitors and removed and reformatted the HDD on a PC. Once reassembled and powered up, it immediately wanted to reformat the disk to the Topfield standard as expected. I felt that this was a good sign, and, for a while, everything was working normally.

However, soon the freezing picture and white noise returned, along with another peculiarity in that the TV would switch off and then immediately switch back on again, as if the PVR was sending numerous off/on signals.

In a final attempt to isolate the fault, I connected the PVR to a small

Continued page 112

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Coming up in Silicon Chip

Subtractive Manufacturing

Dr David Maddison details the history of manufacturing techniques involving devices like mills and lathes, through the early years of numerical control and onto the amazing modern CNC machines. These can create a wide array of shapes out of solid blocks of metal, timber, plastics or other materials with extreme precision and virtually no human labour. He also explains quite a few other modern subtractive manufacturing techniques that you may not be aware of.

Touchscreen RCL Box

This handy device fits into a compact Jiffy box and puts 43 resistance values, 19 capacitance values and 11 inductance values at your fingertips. It can even step through a range of values by itself, to make testing and prototyping really easy for you. Plus it displays the characteristic frequency of various RC, LC and RL combinations.

RTL-SDR dongles with inbuilt upconverters

Following on from the article in this issue, Jim Rowe examines two low-cost off-the-shelf SDRs with inbuilt upconverters. They claim to give significantly better performance than the smaller and cheaper dongles which use the "direct sampling" approach, described in this issue.

Tektronics T-130 'Elcee' Meter

An in-depth look at the operation and restoration of a classic piece of vintage test equipment. This was one of the devices that helped make Tektronics famous. It used some ingenious principles to give extremely accurate and stable inductance and capacitance measurements, with a very clever arrangement of thermionic valves, wafer switches and passive components.

Note: these features are planned or are in preparation and should appear within the next few issues of Silicon Chip.

The June 2020 issue is due on sale in newsagents by Thursday, May 28th. Expect postal delivery of subscription copies in Australia between May 26th and June 12th.

Advertising Index

Altronics 75-78
Ampec Technologies 67
Control Devices ..... OBC
Dave Thompson 111
Digi-Key Electronics 3
Emona Instruments ..... IBC
Hare & Forbes 7
Jaycar IFC,53-60
Keith Rippon Kit Assembly 111
LD Electronics 111
LEACH PCB Assembly 5
LEDsales 111
Microchip Technology 9
Ocean Controls 8
RayMing PCB & Assembly 10
Silicon Chip Back Issues 81
Silicon Chip PDFs 95
Silicon Chip Shop 108-109
Silicon Chip Special Offer 35
The Loudspeaker Kit.com 6
Vintage Radio Repairs 111
Wagner Electronics 99

Philips TV using another HDMI cable. This was our "spare TV" and about 18 months old but with very few hours on it. All seemed well, so I turned down the volume and left it running, confident that if the fault appeared, I would hear the noise.

About an hour later, I discovered that the Philips TV was completely dead, without even the standby light on. Investigations showed that the power supply was delivering all the voltages expected if the TV was in standby, but it could not be roused from that state.

The circuit is basically a tuner, power supply and a megapin IC that seems to be everything else required to make a TV work. As I wasn't watching when it died, I am not sure if there was any unusual display, but I am confident that the PVR 'bricked' the TV via the HDMI.

An internet search showed several people saying that an HDMI connection had damaged their TV, but in nearly every case, there was a reply from a tech 'guru' telling them that they are wrong, that HDMI cannot damage your equipment. I am not so sure now.

I replaced the Topfield with a Panasonic PVR, which can do a lot more, and the problems with the TV have stopped. So am I right in thinking that a faulty device with an HDMI output can damage a television? (B. T., Bonogin, Qld)

● It sounds like your PVR had a fault which was not only interfering with its own operation, but was also delivering voltages to the HDMI cable outside of the normal range. These have confused/damaged the TV(s) via their inputs. Probably your Kogan TV has better protection on the HDMI inputs than the older Philips TV.

You probably aren't surprised to find out that many of these internet 'gurus' think that they know a lot more than they actually do! Unless the connection is galvanically isolated (eg, optically or via transformers), there is always the possibility of damaging voltages travelling from one device to another. We've even seen a USB battery pack fail and 'brick' a charger.

Replacing the PVR was a good idea. It may be possible to repair the old one, but probably not economically. And you risk damaging more TV inputs if you go to test it, thinking you have fixed it, and you haven't. So we'd leave it well alone and move on. SC

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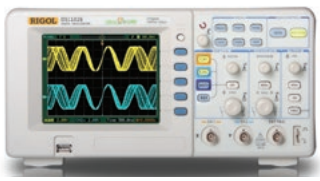

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